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The Calory and the Joule in Thermodynamics and Thermochemistry

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SINCE energy can be measured in a great variety of ways, and since each of these ways provides, after its own fashion, a possible unit of energy, it is only natural that a large number of such units have come into existence. At various times, quantities of energy have been expressed in mechanical units such as ergs, joules, gram centimeters, foot pounds, horsepower hours, liter atmospheres; in thermal units such as calories or British thermal units; or in electrical units, such as watt seconds, kilowatt hours, electron-volts, and so forth. Most readers will recognize these units and many others that can be added to the list.

The first law of thermodynamics was contained implicitly in the work of Carnot[1*] in 1824, of Mayer[2] in 1842 and of Joule[3] in 1843, but was first stated unambiguously by Helmholtz[4] in 1847. Through the first law, it became possible in principle to express each unit of energy in terms of any other, or, alternatively, in any one problem, to express energy in terms of a single unit. This was done in theoretical work long before it became feasible to do so in practice.

For example, in the equation expressing the change in the internal energy of a system as the sum of the heat added (whether thermally, mechanically or electrically), the work done on the system, and the decrease in the kinetic and potential energies, all of these quantities of energy, in theoretical treatments, are expressed in terms of a single unit. In practice, however, the change of internal energy might be expressed in calories; the heat added, partly in calories, partly in joules; the work done, in liter atmospheres; the kinetic and potential energy changes, in kilogram meters. Each of the terms not expressed in calories would require a conversion factor, the reciprocal of a "mechanical equivalent of heat," to make the equation valid. It would have been much simpler to express the change of internal energy in joules, the heat added also in joules, the work done on the system in cubic decimeter centibars [=joules], and so forth.

This paper treats only a small portion of the larger problem, and reviews briefly the present status of the calory and the joule in thermodynamics and thermochemistry, particularly with regard to the actual unit of energy used in calorimetric measurements.

THE THERMAL CAPACITY OF WATER AND THE CALORY

From the early beginnings of calorimetry, in the time of Count Rumford and of Regnault, to the early part of the present century, the most convenient and readily applicable method of measuring quantities of heat arising from proc-

* Superscript numerals indicate the literature references at the end of this paper.

esses occurring at or near room temperature was to observe the rise of temperature produced in a known mass of water contained in a suitable vessel, or calorimeter. In this way, it was possible to measure with considerable precision a quantity of energy in terms of a given mass of water and its rise of temperature. With the calory* defined as the quantity of heat required to raise the temperature of 1 g of water through one centigrade degree, the experimenter was thus able to express the result in calories, obtained as the product of the mass of water in grams and the rise of temperature in centigrade degrees.

As the measurements increased in precision, it became necessary to take proper cognizance of the thermal capacity of the container, thermometer, stirrer, and so forth; to define the scale of temperature; and to specify accurately the various conditions attending the absorption of the heat by the water, such as the mean temperature or the interval of temperature, the pressure, possibly the quantity of air dissolved in the water, and so forth. The specification of the mean temperature gave rise in itself to various calories, such as the 0° calory (cal_0), the 4° calory (cal_4), the 15° calory (cal_{15}), the 18° calory (cal_{18}), the 20° calory (cal_{20}) and the mean calory (0 to 100°C). By about 1905, experimental calorimetry had advanced to a stage where measurements of heat in terms of the thermal capacity of water could be made with a precision of the order of 1 part in 1000.

THE MECHANICAL EQUIVALENT OF HEAT

It was early recognized, however, that, notwithstanding the relative ease with which measurements of heat could be made in terms of the thermal capacity of water, it was necessary to ascertain the equivalent of a given calory in terms of a mechanical unit of energy, such as the erg. This gave rise to the series of investigations begun by Joule about 1840 and continued by him over a long period of years.[3] Following Joule, determinations of the mechanical equivalent of heat were published by Rowland[5] in 1880, by Reynolds and Moorby[6] in 1897 and most recently by Laby and Hercus[7] in 1927. Near the beginning of the present century, extended reviews of the data on the mechanical equivalent of heat were published by Ames[8] and by Barnes.[9] Throughout all this work, it was apparent that the uncertainty of the value giving the number of ergs equivalent to a given calory was always comparable with the uncertainty with which a given quantity of heat could be measured in terms of the thermal capacity of water. As long as this situation existed, it was desirable for purposes of high precision to continue to use as the unit of heat the thermal capacity of water under specified conditions.

UNITS OF ELECTRICAL ENERGY

With the development of accurate electrical standards near the beginning of the present century, it became possible to measure electrical energy with high precision. As soon as this precision in the measurement of electrical energy introduced into a calorimeter became equal to or exceeded that of measuring heat in terms of the thermal capacity of water, the real need for retaining the latter as a unit of heat was removed. It was not until nearly 1930, however, that definite steps were taken to separate the calorimetric unit of heat from any connection with the actual thermal capacity of water under specified conditions of temperature, pressure, and so forth.

Electrical measurements of energy are based upon the second as the unit of time and upon working standards of electromotive force and resistance maintained at the various national standardizing laboratories. The working standards now universally used in these laboratories are wire (usually manganin) resistance coils and saturated cadmium (Weston) cells, which were calibrated in terms of the international ohm and the international volt. When redefined in 1908, the international units, specified in terms of the mercury ohm and the silver voltameter, were identical with the absolute units within the limits with which the latter could then be determined.[10] Since that time, however, the accuracy of the absolute measurements has increased, and more accurate determinations of the absolute ohm and the absolute ampere have been made.[11–20] The

* There are two types of calory in general use, the *gram calory* and the *kilogram calory*. In many cases, the type that is meant must be inferred from the context. In general, the gram calory is used in physics and chemistry; the kilogram calory in engineering and in the biological sciences.

results indicate that the international watt is larger than the watt (mechanical, equal to 10^7 erg/sec) by about 2 parts in 10,000. Specifically,[21–23]

$$1 \text{ international watt (NBS)} = 1.00020 \pm 0.00005 \text{ watts.}$$

The national laboratories certify standard resistors and standard cells in terms of the International units. However, anyone who wishes to do so may convert the values certified by the National Bureau of Standards to the absolute basis by use of the following relations:[21,22]

$$1 \text{ international ohm (NBS)} = 1.00048 \text{ ohms,}$$
$$1 \text{ international volt (NBS)} = 1.00034 \text{ volts.}$$

These values lead to the preceding relation between the international watt and the mechanical watt.

In the course of time, the numerical values of these conversion factors will be subject to small oscillations of unpredictable amplitude, wave form and damping, but the amplitudes are not likely to exceed a few parts in 10^6. Since calorimetry is satisfied with an accuracy of 1 part in 10^4, these oscillations, which are certain to occur from time to time, need not be troublesome. However, careful workers, who aspire to a calorimetric accuracy of 1 part in 10^4, will wish to use the values that are considered authentic at the time their work is done.

It is of interest to note that the values of these conversion factors do not depend in any way upon any changes which may have occurred in the International units as maintained by the national laboratories[24] in the two decades following January 1, 1911, when the units were formally adopted. Their present validity depends only upon the accuracy of the absolute measurements themselves and upon the constancy of the units as maintained during the few years that have elapsed since the time when the most recent absolute measurements, which determine the present conversion factors, were made.

All measurements of electrical energy made since about 1910 by means of standard cells and standard resistors are actually in terms of the international joule. This may also be true of all similar measurements that will be made until such time in the future as the various national standardizing laboratories begin to calibrate standard cells and resistors in terms of absolute units. Before the present war, it had been the expectation of the Advisory Committee on Electricity of the International Committee on Weights and Measures that the old "international" standards defined in 1908—the mercury ohm and the silver voltameter—would be discarded; that the working standards, saturated cadmium (Weston) cells and wire resistors, would be periodically calibrated in terms of the absolute units; and that all the national laboratories would adjust their units, as soon as common international action could be obtained, to absolute values which would be decided upon by the International Committee from the results of the new determinations of the absolute ohm and the absolute ampere.* The transition from the international to the absolute units had been planned to take place in 1940, but the war has postponed completion of the plan.[25]

JOULE *VERSUS* CALORY

Notwithstanding the fact that practically all accurate calorimetric measurements made after about 1910 have been actually based on the international joule (electrical) as the unit of energy, most investigators continued until about 1930 to express their final results in such a way as to make it appear that the unit of energy was in some way still connected with the thermal capacity of water. Actually, what they did was to convert their values, determined in international joules, into one or more of the several calories based on the thermal capacity of water. This procedure should have been reversed; that is, the older data should have been converted to the modern unit of energy; but the conversion to the older unit, the calory, was favored because most chemists and physicists were reluctant to change from their habits of thinking of energy in terms of a unit of the size of the calory.

If it is desired to convert data actually obtained in terms of one of the numerous calories based on

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* It should be pointed out that although the working standards (wire resistors and saturated cadmium cells) of the national standardizing laboratories of England, France, Germany and the United States were given the same values in 1910, those of the different countries have diverged and to some extent have been readjusted since then (reference 26).

the thermal capacity of water, the data given by Osborne, Stimson and Ginnings[27] in their Table 6 may be used. They give values of C_p in mechanical joules per gram degree C, which can be expressed in terms of international joules by using the relation,

$$1 \text{ international joule} = 1.00019 \text{ mechanical joules},$$

which they employed in their calculations.

An important effort to accustom chemists and physicists to the use of the joule as the unit of energy was made by the late Edward W. Washburn in connection with many (but not all) tabulations of thermochemical and thermodynamic values given in the *International Critical Tables*,[28] of which he was Editor-in-Chief. This attempt to change over to the joule was not popular. It appeared then that the calory would at least have to be retained as the name of the thermal unit of energy. It was also realized that there would have to be separated from the new calory every association with the thermal capacity of water, else all the thermodynamic values would have to be changed every time some one determined the thermal capacity of water with an accuracy greater than that already existing. It would also be necessary for the new calory to have a size approximately equal to that of the traditional calory.

The obvious solution was to have an artificial, conventional calory, defined as equal to a given number of international joules, the unit in which the calorimetric measurements are actually made. The investigators would then report their results in terms of the unit in which the measurements are made, and, for the benefit of those who prefer to continue thinking of energy in terms of a unit having the name and size of the calory, would give also values in terms of the artificial calory obtained by using the defined factor for the conversion.

In line with the foregoing development, there came into use independently about 1930 two different artificial, conventional, defined calories,* one in the engineering steam tables and the other in thermochemistry and chemical thermodynamics.

* Known in laboratory parlance as "dry calories."

THE INTERNATIONAL TABLE (I.T.) CALORY

The artificial, conventional calory that is used in the engineering steam tables is designated as the *I.T. calory* (International Table calory), which was defined by the International Steam Table Conference[29] held in London in 1929 by the relation,

$$1 \text{ I.T. calory} = 1/860 \text{ international watt hour} \\ [= 4.1860 \text{ international joules}].$$

As a matter of historical interest, it may be mentioned that the foregoing factor was selected so as to be near the value of the mean (0 to 100°C) calory. As indicated by the definition, the I.T. calory is independent of the thermal capacity or the enthalpy of water.

A discussion of the steam calory and its relation to the calorimetric units of energy then in use was published by one of the present authors shortly after the adoption of an artificial calory for the steam tables.[30]

By common consent, the British thermal unit (Btu) used in current steam tables is defined in terms of the I.T. calory so as to retain the convenient relation,

$$1 \text{ cal/g} = 1.8 \text{ Btu/lb}.$$

THE THERMOCHEMICAL CALORY

The artificial, conventional calory that is used in all the research laboratories in the United States dealing with thermochemistry and chemical thermodynamics is defined completely by the relation,[31–34]

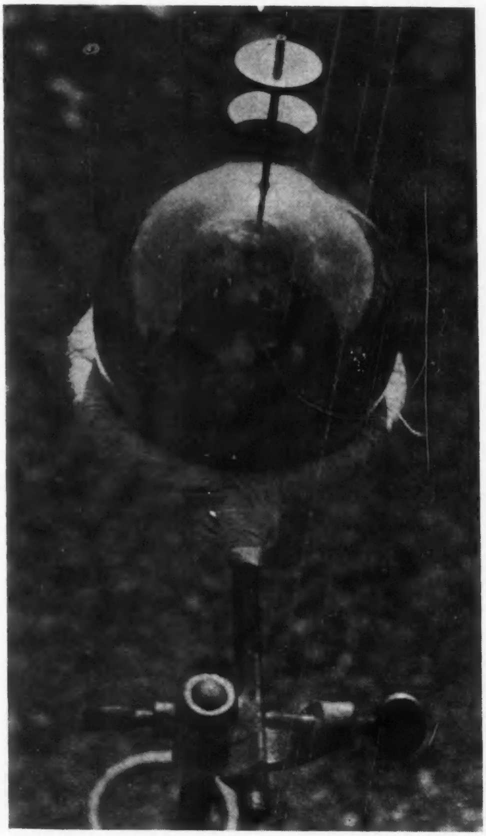
$$1 \text{ calory} = 4.1833 \text{ international joules (NBS)}.$$

As indicated, this calory is independent of the thermal capacity or the enthalpy of water.

The number 4.1833 now has no particular significance, though for historical interest it may b[illegible]ned that it arose from the quotient 4[illegible]004, through the attempt to hold to the f[illegible].185 selected by the *International Critical T*[illegible] for the relation between the absolute j[illegible]nd the 15° calory (cal_{15}), and the factor 1.[illegible]ected in 1930 as the then best ratio of the inte[illegible]tional joule to the absolute joule.[35]

According to the tabulation of Osborne, Stimson and Ginnings,[27] the thermochemical

calory would be, well within the limits of experimental error, equal to 1 cal_{17} or 1 cal_{59}, the



REFLECTIONS ON CALORIMETRY

This stirred calorimeter, approximately spherical, capacity about 1.2 l, was used by Osborne, Stimson and Ginnings in their determinations of the thermal capacity of water in the range 0° to 100°C, and incidentally in evaluating all of the various wet calories in terms of the joule. When in use, the calorimeter was enclosed in two outer shells, the inner one of which was evacuated, while the space between the two contained saturated water vapor, maintained at the temperature required to shield the calorimeter against heat exchange with the surroundings. The two flexible disks appearing above the calorimeter eventually served as the tops of the two shells. The three authors can be seen reflected in the gold-plated surface of the calorimeter.

I.T. calory would be 1 cal_{14} or 1 cal_{65}, and the mean (0° to 100°) calory would be 1 $cal_{11.5}$ or 1 cal_{71}.

UNITS OF ENERGY IN VARIOUS THERMODYNAMIC QUANTITIES

The foregoing discussions have dealt entirely with the unit of energy in calorimetric measurements. The relations among the several common thermodynamic properties which involve energy are shown in Table I, which gives the thermodynamic property, how it is determined, the relation involved, the quantities actually measured by the investigator and the units, the constants involved and their units, and finally, the resultant unit of energy. As may be seen from this table; the resultant units of energy are about equally divided between mechanical joules and international joules, with the latter arising from those measurements that involve international ohms and international volts, either directly in the measurements or indirectly by way of the constant in the relation used to deduce the given property from the measurements made.

CONCLUSION

To summarize, the present status of the unit of energy in modern thermodynamics and thermochemistry may be described as follows:

(1) The actual calorimetric unit of energy is the international joule.

(2) There are in wide use at the present time two artificial, conventional calories which are defined simply as given numbers of international joules, and which are independent of the thermal capacity or the enthalpy of water, as follows:

(*a*) In the engineering steam tables, the artificial calory is defined completely by the relation,

1 I.T. calory = 1/860 international watt hour
[= 4.1860 international joules].

(*b*) In thermochemistry and chemical thermodynamics, the artificial calory is defined completely by the relation,

1 calory = 4.1833 international joules (NBS).

(3) Quantities of energy in thermodynamics that are derived from other than calorimetric measurements have as their actual unit either the international joule or the mechanical joule, as shown in Table I.

(4) When the national standardizing labora-

TABLE I. Units of energy for various thermodynamic quantities.*

Thermodynamic quantity	Method of determination	Relation involved	Quantities actually measured, and the units	Constants involved and the actual units	Resultant unit for the quantity
ΔE, increment of internal or intrinsic energy	(1) Change in mass	$\Delta E = MY\Delta m/m$	m, Δm(g)	Y(j/g) M(g/mole)	j/mole
	(2) Spectroscopically	$\Delta E = Z/\lambda$	λ(cm)	Z(int. j cm/mole)	int. j/mole
ΔH, increment of heat content	(1) Calorimetrically	$\Delta H = Mte^2/mr$	m (g) t (sec) e (int. volt) r (int. ohm)	M (g/mole)	int. j/mole
$T\Delta S$, absolute temperature times increment of entropy	(1) Calorimetrically	$T\Delta S = Mte^2/mr$		M (g/mole)	int. j/mole
	(2) Statistical calculations	$T\Delta S = RT \ln W$	W (independent of the units)	$RT = (PV)_T^{P=0}$ (int. j/mole)	j/mole
ΔF, increment of free energy	(1) Equilibrium measurements	$\Delta F° = -RT \ln K$	K (independent of the units)	$RT = (PV)_T^{P=0}$ (int. j/mole)	j/mole
	(2) Emf of cells	$\Delta F = n\boldsymbol{F}\boldsymbol{E}$	n (independent of the units) $\boldsymbol{E}$ (int. volt)	$\boldsymbol{F}$ (int. coul/mole)	int. j/mole

* Notation: M, molecular weight; m mass; λ, wave-length; t time; e, voltage; $\boldsymbol{E}$, emf; $\boldsymbol{F}$, Faraday constant; r, resistance; R, gas constant; W, probability; K, equilibrium constant.

tories begin calibrating standard cells and resistors in absolute volts and absolute ohms, the actual unit of energy in calorimetric measurements will become the absolute joule (electrical), which will be as nearly equal to 10^7 ergs as present-day measurements will permit. In order to retain the same two artificial calories as are now being used, the definition of the steam calory will become

$$1 \text{ I.T. calory} = (3600/860)(1+a) \text{ mechanical joules,}$$

and the definition of the thermochemical calorie will become

$$1 \text{ calory} = 4.1833(1+a) \text{ mechanical joules,}$$

where $(1+a)$ will be the then best ratio between the international watt and the mechanical watt.

(5) It is to be hoped that in the course of time physical scientists will become more and more familiar with the joule as the unit of energy, thermal or otherwise, and that the arbitrary conversion of joules to artificial calories will become a chore that will gradually cease to be necessary. The speed with which this change may occur will depend very much on how the subject is taught.

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Bad Physics in Athletic Measurements

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THE physics teacher has been accustomed to find in athletic activities excellent problems involving velocities, accelerations, projectiles and impacts. He has at the same time overlooked a rich source of illustrations of fictitious precision and bad metrology. When the student is told that the height of a tree should not be expressed as 144.632 ft if the length of its shadow has been measured only to the nearest foot, the student may see the point at once and yet ask, "What difference does it make?" But when shown that common procedures in measuring the achievements of a discus thrower could easily award a world's record to the wrong man, the student agrees that good technic in measurement is something more than an academic ideal. The present discussion[1] has been prepared partly to give the physics teacher something to talk about, but also to start a chain of publicity which may ultimately make athletic administrators better physicists and so make their awards more just.

If physicists were given charge of the measurements of sport, one may feel sure that they would frown upon the practice of announcing the speed of a racing automobile in six or seven digits—see, for example, the *World Almanac* for any year—when neither the length of the course nor the elapsed time is known one-tenth so precisely. They could and would point out such inconsistencies as that observed in some of the events of the 1932 Olympic games when races were electrically and photographically timed to 0.01 sec, but with the starting gun fired from such a position that its report could not reach the ears of the waiting runners until perhaps 0.03 to 0.04 sec after the official start of the race. In this case, electric timing was used only as an unofficial or semi-official supplement to 0.1-sec hand timing; but it is easy to see that a systematic error of a few hundredths of a second will frequently cause stopwatch timers to catch the wrong tenth.

Scientific counsel on the field would immediately advise judges of the high jump and pole vault to measure heights from the point of take-off instead of from an irrelevant point directly below the bar which should be at the same level but sometimes isn't. Physicists would suggest equipping field judges with surveying instruments for determining after each throw, not only how far the weight traveled but also the relative

[1] Some of the material in this article appeared in a paper by the author in *Scientific American*, April 1937, and is incorporated here by permission of the editors.

elevation of the landing point and the throwing circle. Certainly it is meaningless if not deceptive to record weight throws to a small fraction of an inch when surface irregularities may be falsifying by inches the true merit of the performance.

In shot-putting, for example, a measured length will be in error by practically the same amount as the discrepancy between initial and final elevations, since the flight of the shot at its terminus is inclined at about 45° to the horizontal. For the discus the effect is some three times as serious because of the flatter trajectory employed with this missile, while broad jumpers under usual conditions must be prepared to give or take as much as 0.5 ft, according to the luck of the pit. Meanwhile, the achievements in these events go down in the books with the last eighth or even the last sixteenth of an inch recorded.

At the 1932 Olympic Games an effective device was used to grade the broad-jumping pit to the level of the take-off board before each leap, but the practice has not become general. Athletic regulations, indeed, recognize the desirability of proper leveling in nearly all the field events, but in actual usage not enough is done about it. Since sprinters are not credited with records achieved when blown along before the wind, there is no obvious reason why weight hurlers should be permitted to throw things down hill.

The rule books make no specification as to the hardness of the surface upon which weights shall be thrown, but this property has a significant effect upon the measured ranges of the shot and hammer, since it is prescribed that measurement shall be made to the near side of the impression produced by the landing weight. In a soft surface this impression may be enlarged in the backward direction enough to diminish the throw by several times the ostensible precision of the measurement.

A physicist would never check the identity of three or four iron balls as to mass by the aid of grocers' scales or the equivalent and then pretend that there was any significance in the fact that one of them was thrown a quarter of an inch farther than the others. In measuring the length of a javelin throw, no physicist who wanted to be right to $\frac{1}{8}$ in. would be content to establish his perpendicular from the point of fall to the scratchline by a process of guesswork, but this is the way it is always done by field judges, even in the best competition.

Among the numerous errors afflicting measurements in the field sports, there is none which is more systematically committed, or which could be more easily rectified, than that pertaining to the variation of the force of gravity. The range of a projectile dispatched at any particular angle of elevation and with a given initial speed is a simple function of g. Only in case the end of the trajectory is at the same level as its beginning does this function become an inverse proportionality; but in any case the relationship is readily expressed, and no physicist will doubt that a given heave of the shot will yield a longer put in equatorial latitudes than it would in zones where the gravitational force is stronger. Before saying that the 55-ft put achieved by A in Mexico City is a better performance than one of 54 ft, 11 in. which B accomplished in Boston, we should surely inquire about the values of g which the respective athletes were up against, but it is never done. As a matter of record, the value of g in Boston exceeds that in Mexico City by $\frac{1}{4}$ percent, so the shorter put was really the better. To ignore the handicap of a larger value of g is like measuring the throw with a stretched tape. The latter practice would never be countenanced under AAU or Olympic regulations, but the former is standard procedure.

Rendering justice to an athlete who has had to compete against a high value of g involves questions that are not simple. It will be agreed that he is entitled to some compensation and that in comparing two throws made under conditions similar except as to g, the proper procedure would be to compare not the actual ranges achieved, but the ranges which would have been achieved had some "standard" value of g—say 980 cm/sec^2—prevailed in both cases. The calculation of exactly what would have happened is probably impossible to physics. Although it is a simple matter to discuss the behavior of the implement after it leaves the thrower's hand and to state how this behavior depends upon g, the dependence of the initial velocity of projection upon g depends upon the thrower's form and upon characteristics of body mechanics to which but little attention has so far been devoted.

The work done by the thrower bestows upon the projectile both potential and kinetic energy. In a strong gravitational field, the imparted potential energy is large and one must therefore suppose the kinetic energy to be reduced, since the thrower's propelling energy must be distributed to both. We have no proof, however, that the *total* useful work is constant despite variation of g, nor do we know the manner of its inconstancy, if any. The muscular catapult is not a spring, subject to Hooke's law, but a far more complicated system with many unknown characteristics. The maximum external work which one may do in a single energetic shove by arms, legs or both obviously depends partly upon the resisting force encountered. Only a little outside work can be done in putting a ping-pong ball because the maximum possible acceleration, limited by the masses and other characteristics of the bodily mechanism itself, is too slight to call out substantial inertial forces in so small a mass. The resisting force encountered when a massive body is pushed in a direction that has an upward component, as in shot-putting, does of course depend upon g; and until we know from experiment how external work in such an effort varies with resisting force, we shall not be able to treat the interior ballistics of the shot-putter with anything approaching rigor.

Several alternative assumptions may be considered. If we suppose that the *velocity* of delivery, or "muzzle velocity," v, of the missile is unaffected by variations of g, we have only the external effect to deal with. Adopting the approximate range formula $R=v^2/g$ (which neglects the fact that the two ends of the trajectory are at different levels and which assumes the optimum angle of elevation) we find that the increment of range $\mathrm{d}R$ resulting from an increment $\mathrm{d}g$ is simply $-R\mathrm{d}g/g$. On the more plausible assumption that the *total work done on the projectile* is independent of g, this total to include both the potential and kinetic energies imparted, one obtains as a correction formula,

$$\mathrm{d}R=-\left(1+\frac{2h}{R}\right)R\frac{\mathrm{d}g}{g}, \qquad (1)$$

where h is the vertical lift which the projectile gets while in the hand of the thrower. A third assumption, perhaps the most credible of all, would hold constant and independent of g the *total work done upon the projectile and upon a portion of the mass of the thrower's person.* It is not necessary to decide how much of the thrower's mass goes into this latter term; it drops out and we have again Eq. (1), provided only that the work done on the thrower's body can be taken into account by an addition to the mass of the projectile.

These considerations show that a variation of g affects the range in the same sense before and after delivery, an increase in g reducing the delivery velocity and also pulling the projectile down more forcibly after its flight begins. They indicate also that the latter effect is the more important since, in Eq. (1), $1>2h/R$ by a factor of perhaps five in the shot-put and more in the other weight-throwing events.

One concludes that the *least* which should be done to make amends to a competitor striving against a large value of g is to give him credit for the range which his projectile would have attained, for the same initial velocity, at a location where g is "standard." This is not quite justice, but it is a major step in the right direction. The competitor who has been favored by a small value of g should of course have his achievement treated in the same way.

The corrections so calculated will not be negligible magnitudes, as Fig. 1 shows. They are extremely small percentages of the real ranges, but definitely exceed the ostensible probable errors of measurement. It is not customary to state probable errors explicitly in connection with athletic measurements, but when a throw is recorded as 57 ft, $1\frac{5}{32}$ in., one naturally concludes that the last thirty-second inch, if not completely reliable, must have been regarded as having *some* significance.

ROTATION OF THE EARTH

It is customary to take account of the effects of terrestrial rotation when aiming long-range guns, but athletes and administrators of sport have given little or no attention to such effects in relation to their projectiles. As a matter of fact they should, for at low latitudes the range of a discus or shot thrown in an eastward direction

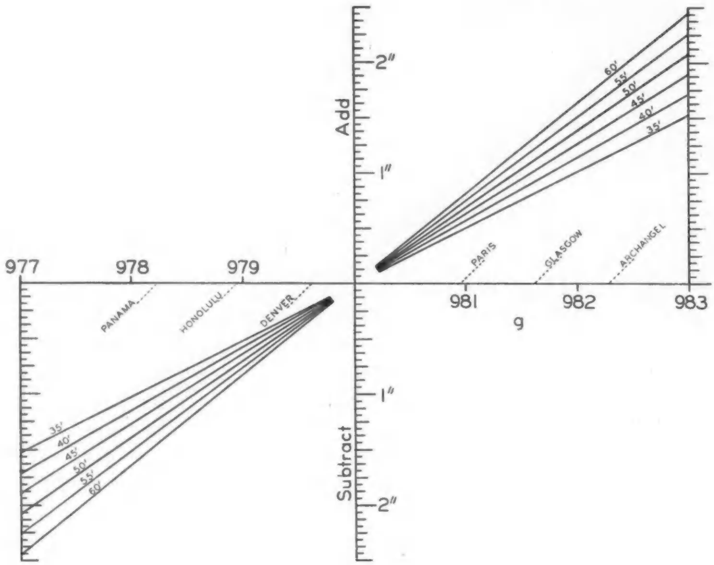

FIG. 1. Graphs for normalizing shot-put ranges to the common value $g=980$ cm/sec². Ranges achieved where $g=980$ cm/sec² are not in need of adjustment, but a range of 50 ft (see inclined line marked 50′) achieved at Glasgow, where $g=981.6$ cm/sec², is entitled to a premium of $1\frac{1}{8}$ in. which should be added before comparing the put with one achieved elsewhere. Distances accomplished where $g<980$ cm/sec² should be subjected to the deductions indicated by graphs in the third quadrant.

exceeds that of a westward throw by more than the ostensible precision of such measurements. The difference between the range of a projectile thrown from the surface of the real earth and the range of one thrown from a nonrotating earth possessing the same local value of g is given by[2]

$$\text{Range}=\frac{V_0^2 \sin 2\alpha}{g}+\frac{4\omega V_0^3}{3g^2} \times \sin \alpha[4 \cos^2 \alpha-1] \cos \lambda \sin \mu, \quad (2)$$

where g is the ordinary acceleration due to weight, V_0 is the initial speed of the projectile, α is the angle of elevation of initial motion (measured upward from the horizontal in the direction of projection), ω(rad/sec) is the angular speed of rotation of the earth, λ is the geographic latitude of the point of departure of the projectile, and μ is the azimuth of the plane of the trajectory, measured clockwise from the north point.

A derivation of this equation (though not the first) is given in reference 2, along with a discussion of its application to real cases. The approximations accepted in the derivation are such as might possibly be criticized where long-range guns are considered, but they introduce no measurable errors into the treatment of athletic projectiles.

The first term of the right-hand member of Eq. (2) is the ordinary elementary range expression, and naturally it expresses almost the whole of the actual range. The second term is a small correction which is of positive sign for eastbound projectiles ($0<\mu<180°$) and negative for westbound. The correction term, being proportional to V_0^3, increases with V_0 at a greater rate than does the range as a whole. Hence the *percentage* increase or decrease of range, because of earth rotation, varies in proportion to V_0 or to the square root of the range itself. Evidently this effect is a maximum at the equator and zero at the poles. Inspection of the role of α shows that the correction term is a maximum for a 30° angle of elevation and that it vanishes when the angle of elevation is 60°.

By the appropriate numerical substitutions in Eq. (2), one may show that a well-thrown discus in tropic latitudes will go an inch farther eastward than westward. This is many times the apparent precision of measurement for this event, and records have changed hands on slimmer margins. Significant effects of the same kind, though of lesser magnitude, appear in the cases

[2] P. Kirkpatrick, Am. J. Phys. 11, 303 (1943).

of the javelin, hammer, shot and even the broad jump, where the east-west differential exceeds the commonly recorded sixteenth of an inch.

Figures 1 and 2 are types of correction charts that might be used to normalize the performances of weight throwers to a uniform value of g and a common direction of projection. Figure 1 has been prepared with the shot-put in mind, but is not restricted to implements of any particular mass. The inclined straight lines of this figure are graphs of $-\mathrm{d}R$ *versus* $\mathrm{d}g$ from Eq. (1). Values of the parameter R are indicated on the graphs. The uniform value 100 cm has been adopted for h, an arbitrary procedure but a harmless one in view of the insensitivity of $\mathrm{d}R$ to h.

Figure 2, particularly applicable to the hammer throw, furnishes means for equalizing the effect of earth spin upon athletes competing with the same implement but directing their throws variously as may be necessitated by the lay-out of their respective fields. An angle of elevation of 45° has been assumed in the construction of these curves, a somewhat restrictive procedure which finds justification in the fact that no hammer thrown at an angle significantly different from 45° is likely to achieve a range worth correcting. These curves are plotted from Eq. (2); their application to particular cases is described in the figure legend.

Upon noticing that some of these corrections are quite small fractions of an inch, the reader may ask whether the trouble is worth while. This is a question that is in great need of clarification and one that may not be answered with positiveness until the concept of the probable error of a measurement shall have become established among the metrologists of sport. Physicists will agree that to every measurement worth conserving for the attention of Record Committees should be attached a statement of its probable error; without such a statement there will always be the danger of proclaiming a new record on the basis of a new performance that is apparently, though not really, better than the old. If the corrections of Fig. 2 exceed the probable error to be claimed for a measurement, then those corrections must be applied.

The aim of the American Athletic Union in these matters is hard to determine. Watches must be "examined," "regulated" and "tested" by a reputable jeweler or watchmaker, but one finds no definition of what constitutes an acceptable job of regulation. Distances must be measured with "a steel tape." The Inspector of

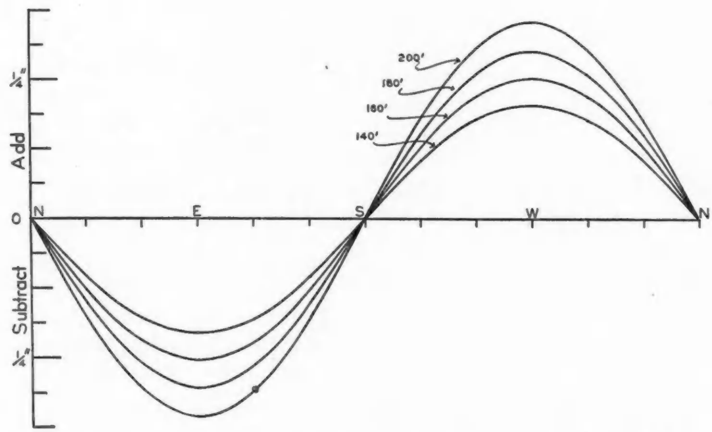

FIG. 2. Curves for rendering throws in various directions comparable. The assumed latitude is 30°, either north or south, and the assumed angle of elevation is 45°. Since the range has a maximum for about this angle of elevation, the curves also apply well to angles several degrees on either side. The curves show, for example (circled point), that a missile thrown 200 ft in a direction 30° south of east should have $\frac{3}{16}$ in. subtracted from its range in order to bring it into fair comparison with unadjusted northward or southward throws or with throws in any other direction which have been adjusted by reference to curves of this type appropriately constructed for their respective latitudes.

Implements must find the weights of the implements "correct." Such ideals of perfection are not realistic, and the only alternative is to recognize the existence of error and state its magnitude. The minimum permissible weight for each implement is prescribed both in pounds and in kilograms by AAU rules, but in no instance are the prescriptions exactly equivalent. A discus thrower whose implement just satisfies the metric specification will use a discus 4 gm, or $\frac{1}{5}$ percent, lighter than that of a competitor whose discus just passes as judged by an inspector using perfect scales calibrated in British units. Those 4 gm will give the former athlete two or three extra inches of distance, an advantage that might be decisive.

Similar comments could be made about the rules of competition of the ICAAAA, where one reads that the javelin throw is measured from the point at which the point of the javelin first strikes the ground. This is a mark that cannot in general be determined to the often implied $\frac{1}{8}$ in. since it is obliterated by the subsequent penetration of the implement. Any javelin throw as correctly measured by ICAAAA rules will show a greater distance than if measured by AAU rules, but few field judges know this nor could they do much about it if they did. It is probable that the rules do not say what was meant in these cases. It is interesting that whereas the hammer, shot and discus must be thrown upon a level surface, there is no such requirement in the case of the javelin.

Any serious attempt to put the measurements of sport upon a scientific basis would be met with vast inertia if not positive hostility. The training of athletes is still very largely an art, and there is no reason to suppose that those who are at present practicing this art with success will be predisposed to changes involving ways of thought which, however commonplace in other disciplines, are novel in athletic competition. One eminent track and field coach, a producer of national, Olympic and world champions, told the writer that he had no interest in hairsplitting; that leveling the ground accurately would be too much trouble; that common sense is better than a wind gage for estimating the effect of wind conditions on sprinters; that a man can't put the shot by theory—it's all in the feeling; that the exact angle of elevation is unimportant as long as he gets it in the groove.

A few years ago, the writer published some criticisms along the lines of the present article and sent reprints to each of the several hundred National Committeemen of the AAU. One acknowledgment was received, but no reactions to the subject matter. In a sense, this indifference was only just recompense for the writer's habit of ignoring communications from nonphysicists proposing novel theories of the atom, or otherwise instructing the physicist as to the foundations of his science.

There probably exists a general feeling that part of the charm of sport resides in accident and uncertainty. Any discussion of the possibility of replacing the balls-and-strikes umpire in baseball by a robot will bring out the opinion that the fallibilities of the umpire are part of the entertainment for which the public pays. An optical instrument for determining from the sidelines whether or not a football has been advanced to first down was tried out in California a few years ago. It was technically successful, but a popular failure. The crowd was suspicious of a measurement that it did not understand and could not watch; the players begrudged the elimination of the breather which a chain measurement affords; and even the linemen protested the loss of their dramatic moment.

Though entertained by such attitudes, the physicist will hardly be able to dismiss a feeling that in any field of popular importance or interest, it is improper to keep up the appearances of accurate and comparable measurement without doing what might be done to gain the reality. In the matter of athletic records, he and very few others know what to do about it.[3]

[3] The author will be pleased to furnish reprints of this article to readers who would find interest in bringing it to the attention of athletic authorities.

THERE is, I think, nothing in the world more futile than the attempt to find out how a task should be done when one has not yet decided what the task is.—ALEXANDER MEIKLEJOHN, in *Education Between Two Worlds*.

The Status of Physics in China

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WHILE it is a well-known fact that in international relations China considers the United States to be her best friend as a natural consequence of America's traditional friendship, few people know that China owes her a real debt likewise in the development of science. Before the dawn of the twentieth century, American missionaries established modern schools in China in which science was included as a part of the curriculum. The writer recalls with pleasure that the first science primer he ever read was a book in Chinese written by the eminent President of St. John's University at Shanghai, Dr. F. L. Hawks Pott. Another American who contributed materially to awakening interest in science, particularly physics, is Professor C. H. Robertson, originally of the Purdue University engineering faculty, who headed the lecture department of the National Committee of the Y.M.C.A. in China. His masterful lectures, for the most part with excellent portable demonstration equipment, on such topics as the gyroscope and the monorail, wireless telegraphy, sound motion pictures and relativity, were given before large audiences of Chinese students during the first quarter of the century, and aroused in them a genuine admiration and interest in the wonders of physics.

The first Chinese who received adequate training in physics in America was John Y. Lee, who worked under Professor Millikan on the measurement of the electronic charge by using solid spheres of shellac falling in air. After his return to China, Lee joined Robertson in planning the popular lectures and also taught physics at several of the government universities as a part-time job. He was soon followed by K. F. Hu who worked with Professor William Duane on the critical absorption and characteristic emission of x-rays, and by K. L. Yen who worked on ionic mobilities under Professor Millikan. Among other earlier students was the present President of the Chinese Physical Society, Dr. Y. H. Woo, who was associated with Professor Arthur Compton in the early experiments that proved the Compton effect. The Boxer Indemnity Scholarships provided a large number of Chinese students with the opportunity for study in the United States; it is natural, therefore, that the greater part of our physics teachers and research men with graduate work abroad received American training. However, there is also a considerable group of our physicists who received their training elsewhere, particularly in Great Britain. In recent years, the return of the British Boxer Indemnity Fund, which came later than the American gesture, is enabling a number of Chinese students to pursue graduate work in Cambridge, London and other centers of physics in Great Britain.

With the return of Chinese students from abroad to join the university faculties in Peiping and Nanking, we began a new era in education. The Southeastern University in Nanking—especially under the leadership of Dr. K. F. Hu, who returned in 1919—began in earnest to train men in physics. Their first graduates were found good enough to enter the graduate schools of American universities such as Harvard and Chicago, Y. H. Woo being among them. Southeastern University started as a normal college under the presidency of Dr. P. W. Kuo, who was trained in education in Columbia University. It is, indeed, a fine tribute to him and Doctor Hu and their institution that quite a number of our leading physicists in China today are graduates of Southeastern University. Tsing Hua and Peita organized their physics departments about the same time as Southeastern and were followed by other provincial and national universities, some after the American pattern and others after the continental pattern. In order to standardize the curriculum, the ministry of education in 1933 began to consult various professors of physics and educators with the objective of formulating a standard curriculum for the various schools and departments in a university.

* Present address, China Defense Supplies, Inc., Washington, D. C. The writer is obliged to Professor P. C. Ho for his suggestions and criticisms.

Table I gives the curriculum for an undergraduate physics major as actually in force in the National Wuhan University, which follows closely the standard curriculum promulgated by the Ministry of Education. The government requirement for graduation is 132 semester hours minimum and 142 maximum. Thus a good student may take an extra load of nine semester hours from the following electives offered:

Electrical engineering (a.c. and d.c.)	3	3
Advanced calculus	3	3
Physical chemistry	3	3
Machine shop practice	No credit.	

These electives may be taken in junior and senior years with the approval of the department of physics.

It is evident that the Chinese student takes fewer liberal courses and more of his major courses as compared with most American students. Also, there is little room for the selection of a minor or other electives. The reason for this is that graduate training is as yet not extensively organized on account of the present economic status of the country. So the student is expected to take his liberal subjects in the middle, or secondary, school; and at the college level he is expected to take more of the professional subjects. With the expected development of graduate schools or institutes, it will become an open question whether we are loading the undergraduate too heavily with a major subject.

The textbooks used in the physics courses are almost entirely in English. The following is the list actually used in Wuhan University during the last year or two:

Course	*Textbook*
General physics	Duff, *et al.*, *Physics*
Electricity and magnetism	Page and Adams, *Principles of electricity*
Heat	Roberts, *Heat and thermodynamics*
Theoretical mechanics	Jeans, *Theoretical mechanics*
Light	Houstoun, *Light*
Radio communication	Glasgow, *Radio engineering principles*
Theoretical physics	Page, *Theoretical physics*
Modern physics	Crowther, *Ions, electrons, and ionizing radiations;* Richtmyer, *Modern physics*
Modern physics laboratory	Hoag, *Electron physics;* Harnwell and Livingood, *Atomic physics.*

For the laboratories, the instructors usually write their own instructions in Chinese. The foregoing list does not include reference books, but our choice during the past three or four years has been influenced by what is available in China. The students usually sell or lend their textbooks to the succeeding class because of textbook shortage.

It can be seen that we are using American textbooks to a large extent. This is not convenient inasmuch as the Chinese student can hardly be expected to understand fully the meaning of the foreign text with his limited training in English in the secondary schools. Further, many examples given which may be of daily occurrence to the American or English student, such as automobiles or refrigerators, are totally strange to the Chinese student, especially if he comes from the interior.

In the early years a number of translations from Japanese physics texts were used, especially in the normal schools because a number of teachers in these schools were trained in Japan. There were also translations from English texts, but most of them were at the general physics level. A very fine book has been written in Chinese by Dr. Arthur P. T. Sah, now president of Amoy University, which is widely used either as a textbook or as a reference book in freshman physics. Some teachers still prefer the use of an English text, because it would be a better preparation for the English texts used during the rest of the college course.

With the temporary dislocation of the colleges at the beginning of the war, a number of temporarily jobless teachers have devoted themselves to the translation or compilation of advanced textbooks in Chinese. In the knowledge of the writer, most of the textbooks in the preceding list have been or are being translated into Chinese. These Chinese texts probably will not displace English texts in the next decade or so, as long as students still look forward to graduate or advanced training abroad, but will serve their very useful purpose in helping the students to understand the English texts better. Eventually, of course, Chinese texts will replace the English texts in the college curriculum, as is already the case in law, economics and the social sciences in general.

Just before the writer left Kiating in March, he asked his colleagues what they would wish to convey to their fellow teachers in the American universities. The answer from the majority of them was that they are hungry for publications—for Western books and periodicals. Since there is no way to send enough books to China because of the high priority of war materials, the Cultural Relations Division of the American State Department has kindly arranged to send microfilms of current periodicals, such as *Nature, Physical Review,* and so forth, to China to be distributed to six of the larger educational centers. This is a real and substantial contribution. With the expected larger and improved production of paper, it may be practical to microfilm some of the latest books and have these reprinted in China.

Another evidence of the dearth of textbooks in China is evidenced by the fact that the British Cultural Attachee in China, Mr. Blofeld, donated to Wuhan University $10,000 for the purchase of commonly used textbooks, which are prohibitive in price, to be placed in common reading rooms, so that each book may be shared by some ten refugee students who have escaped from the occupied areas to enter the University, now located in the western part of Szechuen.

TABLE I. The physics curriculum of the National Wuhan University.

Subject	Semester-hours credit Sem. 1	Sem. 2
Freshman year		
Chinese	3	3
English	3	3
Ethics	1	1
Calculus	4	4
General physics	4	4
General physics laboratory	1*	1*
Chemistry or biology	3	3
Laboratory for above	1*	1*
Total	20	20
Sophomore year		
Chinese history	2	2
Differential equations	3	3
Electricity and magnetism	3	3
Electricity laboratory	1*	1*
Heat and thermodynamics	3	3
Heat laboratory		1*
Theoretical mechanics	3	3
German	3	3
	18	19
Junior year		
Economics, sociology or political science	3	3
Light	3	3
Light laboratory	1*	1*
Radio communication	3	3
Radio communication laboratory	1*	
Properties of matter	3	3
Property of matter laboratory		1*
German	3	3
	17	17
Senior year		
Theoretical physics	4	4
Modern physics	4	4
Modern physics laboratory	1*	1*
Thesis	2	2
	11	11

* Three-hour laboratory.

EFFECT OF WAR ON PHYSICS TRAINING

As a result of war, the colleges migrated to the hinterland according to a plan of balanced distribution of educational institutions throughout Free China. As the Japanese pushed forward, some of the colleges had to move more than once and in one extreme case five times. The universities in the north, which include such fine institutions as Tsing Hua, Peita and Nankai universities, suffered the most as there was not time or means of moving their excellent equipment and libraries; and in the case of Nankai University in Tientsin the Japanese invaders just wantonly destroyed the institution by gun fire and bombs with apparently no military objectives in the vicinity. As North China universities in addition to the Physics Institute of Peiping Academy were actually carrying on research in physics and constituted the strongest center in physics in China at that time, both with respect to the number of physicists there assembled and the experience of the men, the progress in physics naturally suffered a terrific blow. Tsing Hua, however, saved its equipment in electronics, as it was planned before the war to have a research institute in electronics to be established somewhere in South or Central China. The equipment was moved to Hankow, and when it was evident that we could not keep that important city for very long, the equipment was moved to Changsha —which still remains in our possession to this day in spite of three serious Japanese attempts to capture it—and finally to Kunming, where the Associated Southwestern Universities are located, of which Tsing Hua is a part. Other universities

and colleges likewise lost parts of their equipment. This, in addition to the serious blockade and the difficulties of transportation, have worked great hardships on most of the Chinese universities in carrying on laboratory instruction, not to mention research.

GRADUATE TRAINING

The writer belongs to the generation of Chinese students who were entering college about the time of the first world war. At that time we had to go abroad for undergraduate training in science. With the return of more trained men, it has become increasingly feasible to keep the science undergraduate in China. Then, if he proves to be capable of being benefited by further training abroad, by passing government examinations of various kinds he may receive a fellowship to study in America, in Great Britain or in other countries of Europe. This policy has been followed since about 1922. The benefit of keeping the immature student in his own home environment has been real, and the policy has proved to be sound on the basis of national economy. However, when the best students go abroad, there is little opportunity of promoting research in China. Thus when Tsing Hua University started its graduate school about 15 years ago, it experienced difficulty in retaining graduate students. What was even more serious, the graduate students who did remain were more interested in preparing themselves to compete in the examinations than in research, as everyone felt that greater opportunity and prestige would come from studies abroad than in China. The same difficulty still exists today. Perhaps a way out is to emphasize research record rather than success in competitive examinations as a basis for choosing the candidates, or else require four or five years' experience (instead of two) in teaching, industrial work or research before one is permitted to compete for the fellowships. At present, on account of the high living costs not many students want to continue their graduate studies, especially when China so badly needs trained men in every field at the college level. Another drawback to extensive graduate training in China is that we are short of both equipment and libraries. The equipment involved in atomic disintegration experiments is beyond our financial ability at present. As far as the writer is aware, no doctor's degree has as yet been awarded for research work in physics done in Chinese universities.

RESEARCH INSTITUTES

Realizing the importance of research in the advancement of education and industry and human well-being in general, two organizations were set up with the support of the National Government for facilitating and carrying on research; these are the Academia Sinica and the National Academy of Peiping. Academia Sinica was established in 1928 under the Presidency of Dr. Tsai Yuan-pei with ten institutes located in Shanghai and Nanking, and devoted to physics, chemistry, engineering, geology, astronomy, meteorology, zoology and botany, psychology, history and philology and social sciences. The National Academy of Peiping was established in the following year in Peiping and consists of nine sections: physics, radium, chemistry, materia medica, physiology, zoology, botany, geology, historic studies and archaeology. In general, more returned students from America and Great Britain are associated with Academia Sinica and more returned students from France with the National Academy of Peiping. The Institute of Physics of the Academia Sinica was located before the war in Shanghai under the directorship of Professor S. L. Ting, a former student of O. W. Richardson in London. A good machine shop was developed, and it was capable of supplying apparatus for the use of college physics laboratories. This greatly decreased the cost to the educational institutions, at least as far as freight and labor were concerned. Also, it gave us experience and confidence in the design and construction of instruments. In cooperation with the Institute of Chemistry, cathode-ray tubes were manufactured that compared quite favorably with imported tubes. An optical shop was set up with the view of making at least the common types of optical instruments. Another activity of the Institute of Physics was its work in terrestrial magnetism. A magnetic observatory was established on the Purple Mountain in Nanking, the national capital. After the war began, the machine shop was frozen in Shanghai, but it was

possible to take portable parts of the magnetic equipment to Kweilin, Kwangsi. A rather intensive magnetic survey has since been made for the province of Kwangsi. A number of the personnel of the Institute devoted their time to the planning and building of equipment for the wireless network in Kwangsi province. Director Ting spent some time in Hongkong in designing certain equipment suitable for aviation purposes. He was taken prisoner when the Japanese occupied the island, but managed to escape although forced to leave his family behind. With the loss of the equipment in Shanghai and little possibility of replacement on account of the Japanese blockade, the work of the Institute of Physics is being planned over so as to utilize the personnel to contribute their part to the war effort or other work under the difficult circumstances. At present the Institute is located at Kunming.

The physics institute of the National Academy of Peiping under the directorship of Dr. Ny Tsi Ze, a former student of Fabry, did creditable work on pressure effects in photography, piezoelectricity and spectroscopy. Since the war, the institute has moved to Kunming. With its developed technic and experience, the institute has been able to cut and supply crystals and has stabilized more than 1000 transmitters with quartz crystals made in its laboratory. At present its efforts are directed to designing and making optical instruments with the help of other specialists in the universities. Two hundred microscopes were completed in December, 1942 for the Ministry of Education to be used by the colleges, which for the most part are suffering from loss of equipment in the occupied areas and are unable to obtain them from abroad owing to the enemy's blockade. A third contribution of the institute is the adaption of its spectroscopic equipment to meet the needs of the budding metallurgical industry.

It is worth mentioning here that Tsing Hua University since its migration has established at Kunming five research institutes, three of which are related to physics; namely, electronics and radio communication under J. K. Jen (Ph.D., Harvard), metals under Y. H. Woo (Ph.D., Chicago) and aeronautics under C. T. Chuang (M.S., Massachusetts Institute of Technology). In the institute for electronics, the technics for manufacturing of tubes and for short-wave communication are being studied. In the metal institute, x-rays are used for structure study and metallurgical work is being pursued. In the aeronautical institute, work on design and adaption and treatment of native materials as well as theoretical studies is in progress.

THE CHINESE PHYSICAL SOCIETY

The Physical Society was organized about 1932 with the idea of meeting annually and publishing the *Chinese Journal of Physics*. In order to exchange information with our fellow physicists elsewhere, articles are to be written in English, French or German with the abstracts written in Chinese. A number of the annual meetings were held jointly with those of the Science Society of China; but in 1942, when communication had become so difficult and expensive, it was decided that there should be six centers for sectional meetings. Actually, meetings were held in Kunming, Chungking, Chengtu and Kweilin. Some 70 papers were presented, altogether. The following is a random selection of titles of papers presented at the Chengtu and Kweilin meetings:

- Derivation of coefficients of orifices.
- Electromagnet and cloud chambers designed for the investigation of cosmic rays of very high energies.
- A new high tension supply for Geiger-Müller counters. (Vacuum-tube circuit method; China is short of dry cells and storage batteries.)
- A low power apochromatic microscope objective.
- Receiver for ultra-short waves.
- Ultraviolet transmission through specimens of Chinese silk.
- Results of magnetic observations at Chungan, Fukien, during the total eclipse of September 21, 1941.
- Simple substitution method for determining the susceptibility of mineral rocks.
- Effect of iron tube on its magnetizing field.
- Heat treatment of permanent magnetic steels.

In general the papers were theoretical or on new devices to take the place of standard equipment that has been lost on account of the war and cannot be replaced from abroad at present. One paper in the knowledge of the writer was on an automatic self-recording device for measuring the depths of the Chia Ling River at 4-ft intervals. For obvious reasons very little work is being done in nuclear physics and none on high voltages except along theoretical lines.

HANDICAPS OF THE CHINESE PHYSICISTS

During the war years the Chinese physicists have met with real difficulties in many directions. First of all, our library facilities and equipment have suffered on account of losses. Then, during the last three or four years, we have been entirely cut off from the outside world in respect to current periodicals. On top of that, owing to the high inflation, professors in universities have undergone untold hardships in respect to food, clothing and lodging. It is a real wonder that meetings can still be held and papers presented. Textbooks are prohibitive in price, especially for students who have escaped from occupied territory and are entirely cut off from the financial support of their parents. But the spirit of searching after truth and making the most with what we have is still there.

LOOKING TOWARD THE FUTURE

After the war, China will continue to bring about the large-scale industrialization that is already being attempted during these difficult years of war. Engineers are already at a premium. As a result, and in striking contrast with the trend in the United States, pure science—physics included—has lost popularity with students as compared with the situation before the war. But we are confident that the pendulum will return, for physics is the foundation of engineering and industries, and the profession of industrial physicists will be established in due course of time, perhaps soon after the war.

After the war, we shall look to American and British physicists to help train more of our picked graduate students. We shall be grateful if individual universities will see fit to donate to us books and periodicals lost through this war forced on us by the enemy and, if possible, to provide fellowships for our professors and students who want to prepare themselves for the task of China of tomorrow.

At present there are entirely too few physicists in our country—not more than 400* as compared with some 7000 for the United States—of whom perhaps not more than 80 have received the equivalent of the Ph.D. training abroad. According to the China Institute Reports, between 1902 and 1936, 33 Chinese students received doctor's degrees and 17 received the master's degree in physics from American universities, with Chicago leading with 10, Michigan 5, Harvard 4, Princeton 3, Cornell 2, Massachusetts Institute of Technology 2 and the balance among other of the larger universities. In recent years California Institute of Technology has had a number of Chinese students. The returned students from other countries are in the writer's estimate fewer than American returned students, which in another way shows the debt of Chinese physics to American physics.

The war has slowed down our advance, but it has at the same time given us a chance to do the best with what we have. The abnormalities of war have attracted our youth to the applied sciences; it is a challenge to the present generation of Chinese physicists to capture the imagination of students and to win them in sufficient numbers for the science they cherish.

* There were reported to be 281 living members of the Chinese Physical Society in the summer of 1941.

Fall Meeting of the New England Section, American Physical Society

THE twenty-second regular meeting of the New England Section of the American Physical Society was held at the Connecticut College for Women, New London, on October 16, 1943. Forty-five members were in attendance. The program included one contributed paper and the following invited papers:

Discussion of problems connected with the V-12 program. Led by V. E. Eaton, *Wesleyan University*.

Physics at Connecticut College. G. K. Daghlian, *Connecticut College for Women*.

Some simple, large scale models of apparatus developed for first-year college physics. J. Barton Hoag, *U. S. Coast Guard Academy*.

Fast neutron energy absorption in gases, walls and tissue. Gladys A. Anslow, *Smith College*.

Is hardness a physical property of solid matter? S. R. Williams, *Amherst College*.

At the business meeting a resolution was presented on the death of Arthur P. R. Wadlund, who was vice chairman of the Section at the time. The following officers were elected for 1944: Gladys A. Anslow, *Chairman;* Morton Masius, *Vice Chairman;* Mildred Allen, *Secretary-Treasurer;* C. E. Bennett and W. W. Stifler, *Program Committee.*

Mildred Allen, *Secretary-Treasurer*

A Model of the Structure of Rochelle Salt

Frances Pleasonton
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A MODEL of the crystal structure of Rochelle salt was built from a modification of the description given by Beevers and Hughes[1] following their x-ray analysis of the salt. They describe the crystal as orthorhombic, with the space group $P2_12_12$ having the general positions (x, y, z), $(\bar{x}, \bar{y}, z)$, $(\frac{1}{2}+x, \frac{1}{2}-y, \bar{z})$ and $(\frac{1}{2}-x, \frac{1}{2}+y, \bar{z})$. The cell dimensions are given as $a_0=11.93$A, $b_0=14.30$A and $c_0=6.17$A. There are four molecules ($NaKC_4H_4O_6 \cdot 4H_2O$) in the unit cell. Potassium atoms occupy the special positions (*a*) $(0, 0, z)$, $(\frac{1}{2}, \frac{1}{2}, \bar{z})$ and (*b*) $(\frac{1}{2}, 0, z)$, $(0, \frac{1}{2}, \bar{z})$ while the sodium atoms are in positions close to $(\frac{1}{4}, 0, \frac{1}{2})$. The tartrate molecules are oriented diagonally across a projection on the (100) plane; they are tied down quite solidly in the *b* and *c* directions through potassium and sodium atoms but rather loosely in the *a* direction through water molecules. This results in an alternation of layers parallel to the (100) plane which shows the effect of the screw axes quite clearly.

Ionic radii of 0.98 and 1.37A were used for Na[2] (sixfold coordination) and K[2] (eightfold coordination), and H_2O was assigned a radius of 1.38A from its value in the structure of ice.[3] Considerations of contacts within the tartrate molecule led to a choice of 1.33A for the radii of C, O and OH. This is close to the correct value for the radius of the carboxyl oxygen[4,5] but is somewhat less than the usually accepted value of the van der Waals radius for carbon[5,6] and the hydroxyl group.[7]

Balls were chosen from the supply available to represent the atoms on a scale of 1 in. to 2A. The diameters used were: 1 in. for Na; $1\frac{3}{8}$ in. for K and H_2O; and $1\frac{5}{16}$ in. for C, O and OH. This scale gave the unit cell the dimensions: $a_0=5.96$ in., $b_0=7.16$ in. and $c_0=3.08$ in.

First the tartrate molecule was located to give C–C distances of 1.54A, C–O distances of 1.28A at one end and 1.24 at the other end, and C–OH distances of 1.52A. This is a compromise between an ideal molecule,[8] with all similar bonds having the same lengths, and the distorted tartrate group indicated by the results of Beevers and Hughes. The positions of the water molecules and sodium atoms were then adjusted to make the best contacts; only the *z* coordinates of the potassium atoms were shifted, since they occupy the special positions on the twofold axes. This shifting of centers resulted in some change of position for every atom. Six of them had one coordinate changed by 1 or 2 percent of the corresponding cell lengths, six more had two coordinates changed by similar amounts and the remaining five had all three coordinates changed by 1, 2 or 3 percent. The final positions of the balls are given in Table I.

Table I. Coordinates (in.) used for the model.

		x	*y*	*z*			*x*	*y*	*z*
K_a		0.00	0.00	0.20	H_2O	7	2.43	0.61	1.46
K_b		0.00	3.58	0.49	H_2O	8	1.66	0.45	2.59
Na		1.44	7.10	1.53	H_2O	9	2.51	2.08	0.22
O	1	0.73	0.78	1.08	H_2O	10	2.46	2.73	1.45
O	2	1.27	1.45	0.37	C_1		0.86	1.37	0.86
O	3	1.40	2.86	2.50	C_2		0.70	1.98	1.30
O	4	0.33	2.64	2.63	C_3		0.98	1.86	2.01
OH	5	0.87	2.68	1.06	C_4		0.90	2.50	2.43
OH	6	1.72	1.68	1.96					

Figure 1 shows a projection of the structure on the (001) plane. The *z* coordinates are given as fractions of c_0. The dotted lines on the left, marked *a* and *b*, indicate the cell directions and the origin used for the coordinates of Table I.

[1] C. A. Beevers and W. Hughes, Proc. Roy. Soc. **A177**, 251–259 (1941).
[2] Values used by J. D. Bernal and H. D. Megaw, Proc. Roy. Soc. **A151**, 388 (1935).
[3] J. D. Bernal and R. H. Fowler, J. Chem. Phys. **1**, 518 (1933).
[4] L. Pauling, *The nature of the chemical bond* (Cornell Univ. Press, ed. 2, 1940), p. 350.
[5] H. A. Levy and R. B. Corey, J. Am. Chem. Soc. **63**, 2099 (1941); L. Pauling, reference 4, pp. 189–192.
[6] H. A. Stuart, Zeits. f. physik. Chemie **B27**, 353 (1934).
[7] J. D. Bernal and H. D. Megaw, reference 2; M. Magat, Zeits. f. physik. Chemie **B16**, 1 (1932).

[8] A molecule that would conform with the interatomic distances and angles shown by more accurately determined structures, e.g., Levy and Corey, reference 5, p. 2103, and Pauling, reference 4, p. 203.

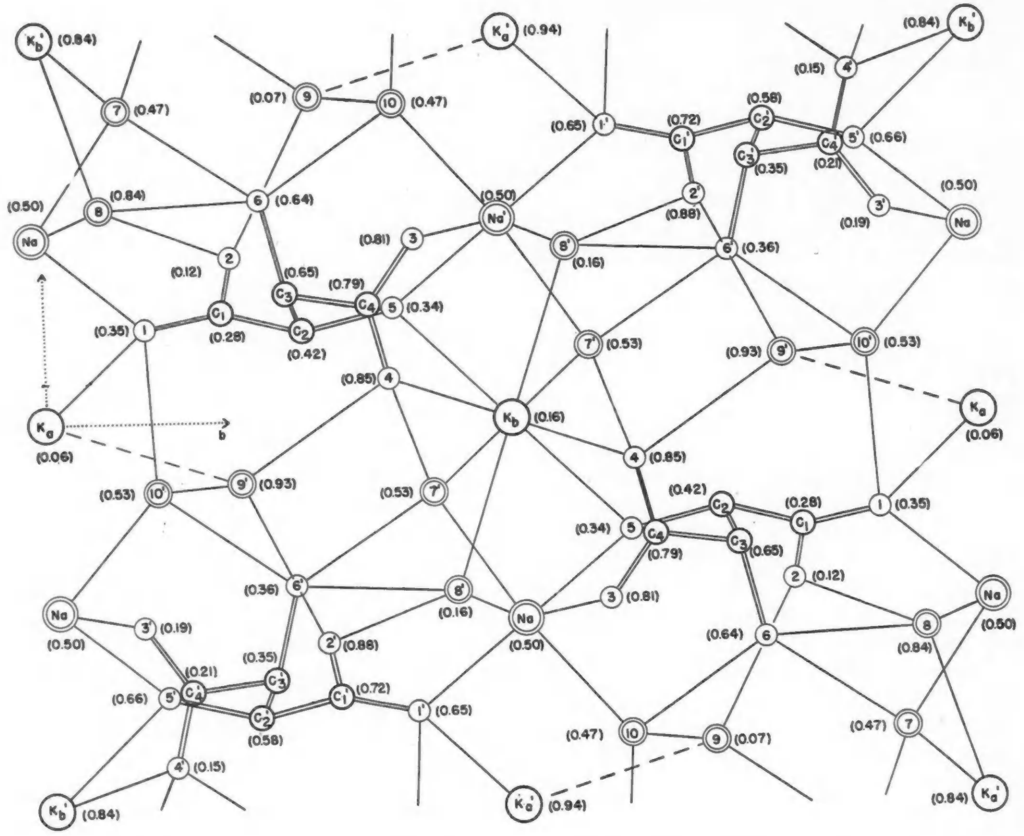

FIG. 1. A projection of the structure on the (001) plane, showing ionic and van der Waals bonding by single lines and covalent bonding by double lines. The circles are labeled with the appropriate symbols for K, Na and C and with numbers corresponding to those given in Table I for O, OH and H_2O.

The dashed lines represent bonds proposed in the original structure but not used for the model since it was impossible to find a position for $H_2O(9)$ that gave four distances short enough for bonding purposes. All equivalent atoms are labeled alike. The primes are used to indicate atoms related to unprimed atoms by the action of a single screw axis; two like symbols (both primed or both unprimed) represent atoms related by the twofold axis. The symbols K_a and K_b are used to distinguish between potassiums occupying the two sets of special positions given in the first paragraph. Figure 2 is a photograph of the model as constructed.

The balls were prepared according to the procedure described by Buerger and Butler,[9] and the holes were made with a drilling machine similar to theirs which orients the holes in terms of the colatitude $\rho = \cos^{-1} [(z_2 - z_1)/D]$ and the longitude $\varphi = \tan^{-1} [(x_2 - x_1)/(y_2 - y_1)]$. The polar axis was chosen in the z direction and the zero for φ along the y axis as indicated in Fig. 3. Initial holes, at $\rho = 0°$, were drilled $\frac{3}{8}$ in. deep in all balls except the potassiums in which they were drilled all the way through. After the balls were painted, the holes for bonding were drilled from the coordinates given in Table II. They were made $\frac{1}{8}$ in. in diameter and $\frac{3}{8}$ in. deep, except

[9] M. J. Buerger and R. D. Butler, Am. Mineral. **21**, 150 (1936).

for those used for bonding within the tartrate molecule which were drilled to the center of the balls. Drawings of the type shown in Fig. 4 were made to facilitate identification of the holes.

Within the tartrate molecule the close approach due to the covalent bonding required the removal of "caplike" portions of the balls, as suggested by Stuart[6] and Magat.[7] This was done by holding the balls against very coarse sandpaper mounted on the face of a disk which was rotated at high speed in a lathe. A guide circle for the grinding was marked on the surface of a ball by a ball-pointed compass centered on the bonding hole and set for a distance R equal to the chord determined by the cap. The geometry necessary to obtain R and the radius of section x is indicated in Fig. 5. Since all the balls concerned have the same radius, the size of cap removed depends only on the interatomic distance. Table III gives the values of x and R needed for grinding the balls, grouping them by the four different bond lengths used. Thus all balls in a given group have equal caps removed.

In order to avoid too many settings of the compass, all circles with the same chord length were marked at one time and the balls ground down to meet them. Each face was then im-

TABLE II. Data used in preparing the balls.

Atom or molecule		Ball diam. (in.); No. used	Bonded to	Drilling coordinates (deg) ρ	φ
O Gray	1	$1\frac{5}{16}$; 8	K_a	129.6	223.1
			C_1	110.1	12.4
			Na	67.8	139.8
			10′	66.4	273.2
O Gray	2	$1\frac{5}{16}$; 8	8	128.5	158.7
			9	96.2	63.1
			C_1	40.0	259.0
O Gray	3	$1\frac{5}{16}$; 8	Na′	144.3	12.0
			C_4	96.5	234.3
O Gray	4	$1\frac{5}{16}$; 8	7′	137.1	290.6
			C_4	108.8	103.8
			9′	80.6	215.1
			K_b	46.7	340.7
OH Yellow	5	$1\frac{5}{16}$; 8	K_b	114.4	316.0
			C_2	71.6	193.7
			Na′	65.5	38.6
OH Yellow	6	$1\frac{5}{16}$; 8	10	111.7	35.2
			7	111.2	146.4
			C_3	86.2	283.7
			8	62.8	182.8
C_1 Black		$1\frac{5}{16}$; 8	2	140.0	79.0
			1	69.9	192.4
			C_2	55.2	345.3
C_2' Black		$1\frac{5}{16}$; 8	C_3'	157.2	66.8
			5′	71.6	166.3
			C_1'	55.2	14.7
C_3 Black		$1\frac{5}{16}$; 8	C_2	157.2	293.2
			6	93.8	103.7
			C_4	57.0	352.9
C_4 Black		$1\frac{5}{16}$; 8	C_3	123.0	172.9
			3	83.5	54.3
			4	71.2	283.8
K_a' Blue		$1\frac{3}{8}$; 12	1′	129.6	136.9
			1′	129.6	316.9
K_b Blue		$1\frac{3}{8}$; 15	4	133.3	160.7
			4	133.3	340.7
			8′	90.0	71.2
			8′	90.0	251.2
			5	65.6	136.0
			5	65.6	316.0
			7′	36.2	42.0
			7′	36.2	222.0

TABLE II—*Continued.*

Atom or molecule		Ball diam. (in.); No. used	Bonded to	Drilling coordinates (deg) ρ	φ
Na′ Red		1; 12	8′	152.0	336.7
			5	114.5	218.6
			10	94.7	130.6
			7′	86.7	304.1
			1′	67.8	40.2
			3	35.7	192.0
H_2O Green	7	$1\frac{3}{8}$; 8	4′	137.1	69.4
			Na	86.7	235.9
			6	68.8	326.4
			K_b'	36.2	138.0
H_2O Green	8	$1\frac{3}{8}$; 8	Na	152.0	203.3
			6	117.2	2.8
			K_b'	90.0	108.8
			2	51.5	338.7
H_2O Green	9′	$1\frac{3}{8}$; 8	10′	152.2	184.4
			4	99.4	35.1
			2′	96.2	296.9
H_2O Green	10	$1\frac{3}{8}$; 8	9	152.2	175.6
			Na′	85.3	310.6
			6	68.3	215.2
			1′	66.4	86.8

TABLE III. Additional data for balls of the tartrate molecule.

Bond	Interatomic distance (in.)	Chord R (in.)	Radius of section x (in.)
C−C	0.77	0.60	0.53
C−O(1,2)	0.64	0.66	0.57
C−O(3,4)	0.62	0.68	0.58
C−OH(5,6)	0.76	0.61	0.54

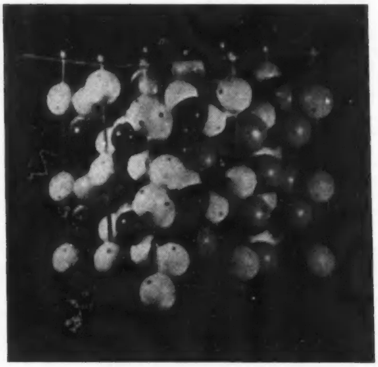

FIG. 2. The completed model including two cell depths. The origin of coordinates lies on the center rod of the left-hand face. The c axis is vertically upwards, the a axis to the left rear, and the b axis to the right rear. Figure 1 is thus a plan of the model as shown.

mediately labeled with the symbol of the ball itself, in red, and with the symbol of the ball to which it would be bonded, in black. Since the initial hole lies outside the caps on the carbons, the drawings could still be used for identifying the holes for the next set of guide circles.

Three layers of potassiums were included to outline the two cell depths constructed. Since some of them were left without any bonds they were all mounted on long rods passing completely through them. The model was assembled by working through successive quarter-cells and setting the corner rods in a base board as the

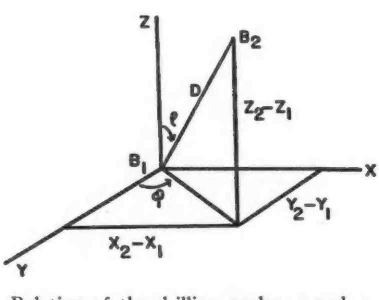

FIG. 3. Relation of the drilling angles, ρ and φ, to the coordinates of the balls.

potassiums were reached. The initial holes of the other balls, drilled at $\rho=0°$, were used in that position (facing upwards) in the unprimed quarters, but turned to $\rho=180°$ in the primed quarters. $H_2O(9)$ and C_2 appear with their initial holes in reverse orientation since their angles were figured for the primed positions.

It was impossible to make perfect contact between all bonded balls since, in many cases,

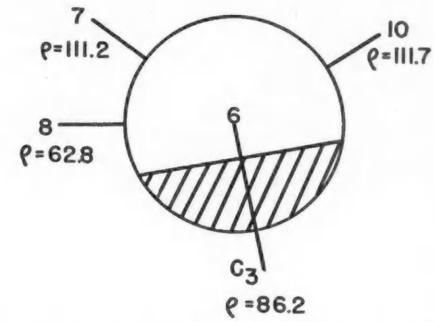

FIG. 4. Type of drawing made for identification of the holes. The equator is in the plane of the paper with $\rho=0°$ directed upwards. Only the ρ values are given since the relative φ positions are obvious.

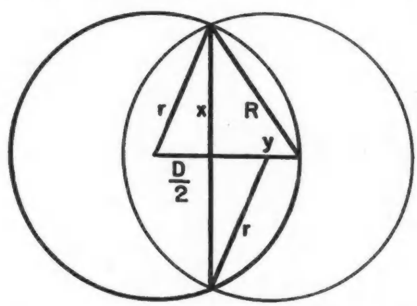

FIG. 5. A cross section of two balls of the tartrate group showing the chord R and radius of section x. These are determined by the equal radii r and the intercenter distance D. The depth of the cap is shown by y.

the intercenter distances were somewhat larger than the sums of the radii. This caused particular difficulty in fitting in $H_2O(9)$ and $OH(6)$, and so some of their bonds were dropped and the balls allowed to show gaps. As a result the model has the dimensions $a_0=6.12$ in., $b_0=7.62$ in. and $c_0=3.17$ in., thus showing expansions of 3, 6 and 3 percent, respectively, over those planned for it.

The author wishes to express her appreciation of the valuable suggestions given by Professor A. L. Patterson in directing the work and of the assistance of Miss F. Morfoot in preparing the balls.

The Doppler and Echo Doppler Effect

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THE Doppler effect is a wave phenomenon the observation and explanation of which readily excite the interest of the physics student. A striking and particularly illustrative case of Doppler change in frequency was experienced some time ago. A swiftly moving automobile was traveling along a highway closely paralleling a railroad track. A freight train was slowly approaching. The sound of the laborious puffs of the engine could be plainly heard and likewise the individual puffs of smoke could be seen. It was soon realized that the frequency of the puff as heard was noticeably higher than the frequency as visually observed. In this case, the Doppler change was not only heard but, so to speak, it was also seen. As the engine went by, the change to a lower pitch was more striking than is usual since the frequency of the puffs as heard was lower than their frequency as seen. Ordinarily one does not have visual evidence of the reality of the Doppler change since the originating frequency under the conditions of motion cannot be separately observed.

Recently the writer had occasion to study the Doppler effect in some detail. As frequently happens when one undertakes such a study, it revealed some facts and ideas that had not come to his attention before. In particular, the role of a reflecting surface moving in the wave train had not been appreciated. Since a fairly thorough search in textbooks of physics and treatises on sound indicated that the usual presentation of the subject is incomplete, the present discussion is offered as a small contribution to the welter of elementary physics literature.

DIFFERENT SITUATIONS GIVING RISE TO DOPPLER EFFECT

There are at least 16 situations that call for separate analysis and setting up of a simple formula relating the initial frequency of sound or light and the new frequency resulting from the separate motions of generating source, detector and reflecting surface. These 16 separate situations are listed herewith.

I. Generator moves with velocity v_g toward a fixed detector.

II. Detector moves with velocity v_d toward a fixed generator, or toward a given wave train.

III. Generator moves with velocity v_g away from a fixed detector.

IV. Detector moves with velocity v_d away from a fixed generator, or away from a given wave train.

V. Generator with velocity v_g and a detector with velocity v_d move toward each other.

VI. Generator with velocity v_g and a detector with velocity v_d move away from each other.

VII. Reflector, fixed, sends back an echo to a detector that is moving toward the reflector on the same vehicle as the moving generator; $v_g = v_d$.

VIII. Reflector, fixed, sends back an echo to a detector that is moving away from the reflector on the same vehicle as the moving generator; $v_g = v_d$.

IX. Generator with velocity v_g and a detector with velocity v_d move in the same direction; the detector is moving ahead of the generator.

X. Generator with velocity v_g and a detector with velocity v_d move in the same direction; the generator is moving ahead of the detector.

XI. Reflector moves with velocity v_r toward a fixed generator and a fixed detector on the same vehicle as the fixed generator.

XII. Reflector moves with velocity v_r away from a fixed generator and a fixed detector on the same vehicle as the fixed generator.

XIII. Reflector with velocity v_r and a generator with velocity v_g move toward each other; the detector is located on the same vehicle as the generator.

XIV. Reflector with velocity v_r and a generator with velocity v_g move away from each other; the detector is located on the same vehicle as the generator.

XV. Reflector with velocity v_r and a generator with velocity v_g move in the same direction, with the detector located on the same vehicle as the generator; the reflector is moving ahead of the generator and detector.

XVI. Reflector with velocity v_r and a generator with velocity v_g move in the same direction, with the detector located on the same vehicle as the generator; the generator and detector are moving ahead of the reflector.

DERIVATION OF FORMULAS

In simple arguments to obtain the formula for the few cases of the Doppler effect generally presented, the usual method is to picture a train or a group of waves before and after the apparent change in frequency. Then it is pointed out that the train of waves is squeezed into a smaller distance and hence that there is an increase in

frequency. Such expressions as "the waves in a given space are now crowded into a smaller space" and "the waves are crowded together in front" had never been satisfying to the writer in considering the mechanism of the wave phenomena for the purpose of obtaining the simple formulas covering the situation. To picture the train of waves existing after the change in frequency is not entirely intellectually honest. It is like assuming an answer to a problem before one has worked out the answer. It seems better to put the burden of proof and to center the attention on a single wave and, as it were, apply a high speed motion picture camera to the mechanics of what happens in a single wave rather than to picture a train of waves and apply equations after the crux of the phenomenon has occurred. What happens at a particular instant to an individual wave happens in like manner to all subsequent waves. Simple equations apply to one wave and therefore cover the situation for the entire ensemble of waves.

Case I. Generator moves with velocity v_g toward a fixed detector.—Let a fixed generator—say, of sound—send out a train of waves toward a fixed detector. The situation is indicated in Fig. 1, for the instant when a new wave front is about to be emitted by the generator. At this instant, let the generator start to move toward the detector with velocity v_g. Then after a short time—less than the period—the situation is as shown in Fig. 2. The generator has moved to position G_1 while the wave front has moved to A. Hence the wave-length now is no longer the distance λ but is shorter, namely, λ_n.

The velocity of the wave front is c, and that of the generator is v_g; the relative velocity is $c-v_g$, hence

$$\lambda_n=(c-v_g)/f,$$

where f is the frequency.

The reduced distance between condensations means that they strike the detector more frequently, and so the pitch is increased; the new

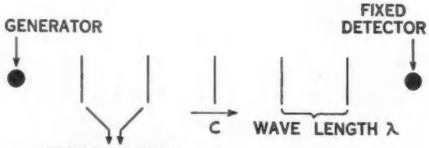

FIG. 1. Fixed generator and fixed detector.

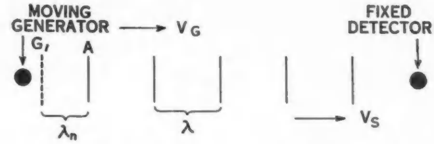

FIG. 2. Generator moving toward a fixed detector (Case I).

frequency is

$$f_n=\frac{c}{\lambda_n}=\frac{c}{c-v_g}f. \tag{I}$$

If f is 500 vib/sec, c is 1130 ft/sec and v_g is 50 ft/sec (34 mi/hr), f_n is 523.2 vib/sec; thus an "up Doppler" shift of 23.2 vib/sec results.

Our slow-motion picture of the mechanics of the situation indicates, then, an actual physical shortening of the wave-length of the waves comprising the sound stream. The resultant frequency change is a secondary effect.

Case II. Detector moves with velocity v_d toward a fixed generator, or toward a given wave train.—In Fig. 3 is shown the arrangement for the converse situation of Case I. Again the approach is to consider the situation before and after the moment at which motion begins. Condensations which are a distance λ apart have been impinging upon the detector. After the detector starts to move toward the oncoming waves, the wave-length is still λ, but instead of the condensations striking the detector more frequently because they are closer together, as in Case I, now the detector strikes them more frequently on account of its motion. There is no physical change in wave-length. The resultant frequency change is not a secondary but a primary effect.

The relative velocity of condensations and detector is $c+v_d$, and $\lambda=c/f$; therefore,

$$f_n=\frac{c+v_d}{\lambda}=\frac{c+v_d}{c}f=f+\frac{v_d}{c}f. \tag{II}$$

If f is 500 vib/sec and v_d is 50 ft/sec—the same values as in Case I—the new frequency is 522.1 vib/sec. An "up Doppler" effect of 22.1 vib/sec results.

It is to be noted that the "up Doppler" effects in Cases I and II are not exactly the same, a fact that might not be obvious without an analysis. Before discussing why they are not the same, we will pass to Cases III and IV, since they offer further evidence apropos of this specific aspect of the general problem.

Case III. Generator moves with velocity v_g away from a fixed detector.—Here the relative velocity of a generator moving in one direction and condensations moving in the other is $c+v_g$. There is an increase in wave-length as contrasted to the shortening in Case I; that is, $\lambda_n=(c+v_g)/f$, or

$$f_n=\frac{c}{c+v_g}f, \tag{III}$$

a "down Doppler" effect.

If f is 500 vib/sec and v_g is 50 ft/sec, as before, the new frequency is 479.0 vib/sec; the frequency shift is 21.0 vib/sec, not 23.2 as in Case I.

Case IV. Detector moves with velocity v_d away from a fixed generator or away from a given wave train.—In this situation the wave-length is unchanged, as in Case II. The relative velocity of condensations and detector is $c-v_d$; therefore,

$$f_n=\frac{c-v_d}{c}f=f-\frac{v_d}{c}f. \tag{IV}$$

Comparison of this formula with that of Case II shows that as much is to be subtracted here as was added in Case II. Hence the "down Doppler" shift is exactly the same as the "up Doppler" when the detector moves, namely, 22.1 vib/sec.

VARIATION OF DOPPLER EFFECT

In Cases I and III, there was a real and primary change in wave-length. These changes were exactly the same in magnitude; 2.26 ft was the original wave-length, 2.16 ft that in Case I and 2.36 ft that in Case III. These equal changes in wave-length did not effect equal changes in frequency. The reason will become clear by considering Fig. 4, which shows the relation between λ and f in sea water. The quantities λ and f are not linearly related; their product is a constant, namely, the velocity of sound. Hence their graph is a hyperbola, and equal changes in one do not produce equal changes in the other. The shaded areas are made to illustrate this fact. Equal frequency differences on the f axis produce widely different changes of wave-length on the λ axis. Likewise, if equal differences of wave-length are taken on the λ axis, the corresponding frequency changes are widely different.

In voice and music transmission by radio and wire, the specifications for good transmission must always be given in terms of frequency, since frequency range is the real criterion of vocal and musical reproduction. For whatever carrier frequency one chooses to select, this specification is always the same. The wave-length range will not be the same at different wave-lengths, as is evident from Fig. 4. Wave-length in this case is a secondary, not a primary matter. In Cases II and IV, the change is a direct and primary change in frequency; hence the changes are exactly equal, namely, $\pm(v_d/c)f$.

VELOCITY OF GENERATOR AND DETECTOR EQUAL TO THAT OF SOUND

The formulas of Cases I to IV bring out some interesting facts if it is assumed that v_g or v_d is equal to c. In Case I, when $v_g=c$, the resultant frequency would be infinite. If $v_g=\frac{1}{2}c$, then the new frequency is the octave above the original. An airplane can travel 375 mi/hr, which is $\frac{1}{2}c$. It would be possible that the roar of an airplane engine could appear to be the octave above its normal roar.

If the generator moves away with velocity c (Case III), the pitch is the octave below.

When the detector moves with velocity c toward a fixed generator (Case II), the pitch would be the octave above. This result contrasted to the foregoing case where the frequency would be infinite again illustrates the basic difference in a primary wave-length change and a primary frequency change.

The frequency received by a detector moving with velocity c away from a fixed generator would be zero; in other words, the detector would retreat so fast that no tone would be heard.

Case V. Generator with velocity v_g and detector with velocity v_d move toward each other.—An increase in pitch results when both generator and detector move toward each other; for, combining Cases I and II, we have

$$f_n=\frac{c+v_d}{c-v_g}f. \tag{V}$$

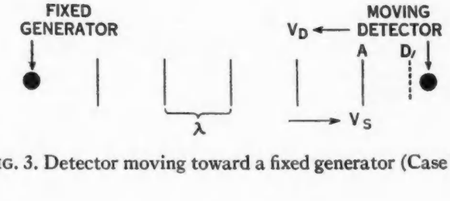

Fig. 3. Detector moving toward a fixed generator (Case II).

Case VI. Generator with velocity v_g and detector with velocity v_d move away from each other.—Combining Cases III and IV, we have

$$f_n=\frac{c-v_d}{c+v_g}f. \qquad \text{(VI)}$$

ECHO DOPPLER EFFECT INVOLVING A FIXED REFLECTOR

In Cases VII and VIII a fixed reflector serves to send back an echo to a detector that has the same velocity as the generator. Since the fixed reflector serves only to effect a change in direction, the formulas are readily written down. Likewise, equations for Cases IX and X can readily be formulated from Table I. In this table, the algebraic sign of v_g is positive if the generator moves in a direction opposite to that of the waves sent toward the detector; v_g is negative if the generator moves in the same direction as the waves. The sign of v_d is positive if the detector moves toward the oncoming waves and is negative if it moves away from oncoming waves. Expression (3) is a general one; (1) and (2) are special cases readily obtained by substituting 0 for v_d or v_g in (3).

MOVING REFLECTOR

Case XI. Reflector moves with velocity v_r toward a fixed generator and a fixed detector.—Assume that a fixed generator sends out a pulse, or short wave train, which strikes a reflector moving toward the generator. The reflected pulse is received as an echo by a fixed detector at the position of the generator.

The mechanism of the reflection phenomena is pictured in Fig. 5, in which C_1, C_2 and C_3 are ongoing condensations, C_4 has just reached the reflector, and C_5, C_6 and C_7 are condensations that have been reflected while the reflector was at rest. Assume that the reflector starts to move at the instant C_4 reaches it. Then C_3 will meet the reflector R at position M. The relative velocity of C_3 and R is $c+v_r$, so that C_3 meets R at a time $\lambda/(c+v_r)$ after R starts to move. The distance OM traveled by C_3 during this time is $c\lambda/(c+v_r)$. While C_3 has been traveling from O to M, C_4 reflected from R has traveled back toward the detector an equal distance from R to X, or $OM=RX$. Thus a condensation C_3 is at M and the next condensation C_4 is at X, so the wave-length λ_f is now the distance between M and X. But $MX=OM-OX=OM-(\lambda-OM)=2OM-\lambda$; hence

$$\lambda_f=\frac{2c\lambda}{c+v_r}-\lambda=\lambda\left(\frac{2c}{c+v_r}-1\right)=\frac{c}{f}\left(\frac{2c}{c+v_r}-1\right),$$

and

$$f_f=\frac{c}{\lambda_f}=\frac{c+v_r}{c-v_r}f, \qquad \text{(XI)}$$

an "up echo Doppler" effect.

It is interesting to observe that this Case XI is a combination of a shortened period in the first part, where C_3 and R meet in less time than if C_3 had to go all the way to a fixed reflector at R, and also a shortened wave-length, since C_4 does not travel all the way to Y before the next condensation C_3 starts after it.

The frequency f_n that would be received by a detector *on the reflector* is

$$f_n=\frac{c+v_r}{c}f.$$

The situation of Case XI is the same as that of Case I with a moving generator of this frequency f_n sending a train of

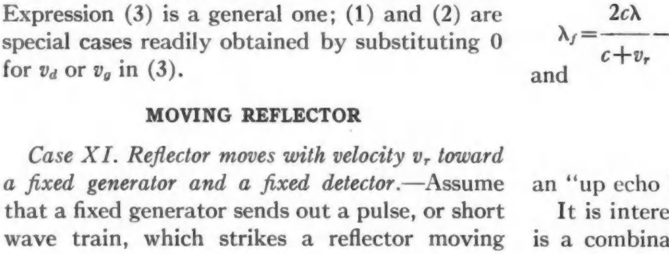

FIG. 4. Wave-length *versus* frequency for sound in sea water.

waves toward a fixed detector. Then

$$f_f=\frac{c}{c-v_r}f_n=\frac{c+v_r}{c-v_r}f.$$

For the numerical values used in the examples of Cases I and II, the "up Doppler" shift of Case XI turns out to be 46.0 vib/sec. This is about twice as much "up Doppler" shift as those of Case I (23.2) or Case II (22.1), or about their sum, 45.3 vib/sec.

TABLE I. Doppler formulas for Cases I to X; c, velocity of sound; f, frequency of generator.

Velocity of generator, v_g	Velocity of detector, v_d	Frequency received by detector
$\pm v_g$	0	$\frac{c}{c\mp v_g}f$ (1)
0	$-v_d$	$\frac{c\pm v_d}{c}f$ (2)
$\pm v_g$	$-v_d$	$\frac{c\pm v_d}{c\mp v_g}f$ (3)

The motion of the detector in Case II meant that an ongoing condensation had to travel a shorter distance (a decrement in wave-length) to be received than if the detector were fixed. Similarly, in this Case XI, not only does the ongoing condensation C_3 travel a shorter distance in meeting the reflector than it would if the reflector were at rest, but also there is a second decrement, namely, the distance by which C_3 is behind its predecessor condensation C_4. Hence the formula for Case XI is sometimes written not in the form of Eq. (XI) but as

$$f_n=f+\frac{2v_r}{c}f. \qquad \text{(XI}')$$

This looks like Eq. (II) with a coefficient 2 inserted. It expresses the approximation that if a shortened distance adds a fractional frequency $(v_d/c)f$ to the final frequency f of Case II, twice that shortened distance would add twice the fractional frequency. With this approximate formula, Eq. (XI′), the "up Doppler" shift turns out obviously to be twice 21.2, or 42.2 vib/sec, instead of the correct value, 46.0 vib/sec.

Case XII. Reflector moves with velocity v_r away from a fixed generator and a fixed detector.—In this case (Fig. 6), condensation C_3 at O must catch up with the retreating reflector R and does

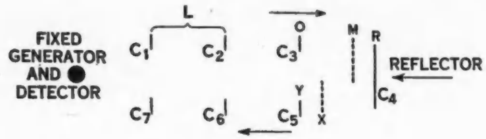

FIG. 5. Reflector moving toward a fixed generator and detector (Case XI).

so at M. It must gain a wave-length λ from O to R; hence the time required to overtake R with relative velocity $c-v_r$ is $\lambda/(c-v_r)=T$. Thus C_3 gains a wave-length but to do so must travel a distance greater than λ, namely, the distance $OM=c\lambda/(c-v_r)$.

As C_3 has been catching up and traveling more than the distance λ, so C_4 reflected from R will travel back more than a wave-length, namely, the distance RX. Thus the original wave-length λ was lengthened first to OM and second to MX; it received two equal increments, RM and YX. Hence the final wave-length is $\lambda_f=MR+RY+YX=\lambda+2MR=2OM-\lambda=\lambda(c+v_r)/(c-v_r)$ and

$$f_f=\frac{c-v_r}{c+v_r}f, \qquad \text{(XII)}$$

a "down echo Doppler" effect.

The frequency assumed to be received by a fictitious detector on the reflector owing to the reflector's moving away from the oncoming waves is, as in Case IV,

$$f_n=\frac{c-v_r}{c}f=f-\frac{v_r}{c}f.$$

Again it is to be pointed out that the results are the same as if a separate generator with the frequency f_n and retreating from a fixed detector were sending a train of waves toward the latter, as in Case III. Substitution of the foregoing value of f_n for f in Eq. (III) gives Eq. (XII).

With the same numerical values as previously, the "down Doppler" shift of Case XII turns out to be 42.4 vib/sec. This is about twice as much

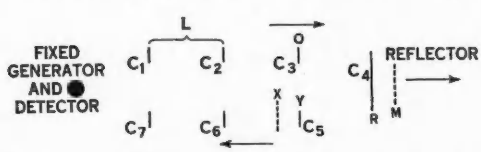

FIG. 6. Reflector moving away from a fixed generator and detector (Case XII).

"down Doppler" shift as those of Cases III and IV, or about equal to their sum.

In Case IV the recession of the detector meant that an ongoing condensation had to travel a longer distance to be received than if the detector were fixed, so that there was an increment in the wave-length. Since in Case XII there are two equal increments, it may be argued that if one increment of distance produces a fraction fv_r/c to be subtracted from f, a second equal increment of distance would double the fraction to be subtracted. Thus we would write the approximate formula,

$$f_n = f - \frac{2v_r}{c} f,$$

which may be compared with Eq. (IV).

If this formula is used with the same numerical values as before, the "down Doppler" shift is obviously twice that of Case IV (22.1), namely, 44.2 vib/sec, which is close to the actual value. However, the assumption that the effect of a double increment of distance is a double decrement of frequency is not valid, as has already been pointed out (Case XI).

Cases XIII to XVI.—The formulas for these cases are obtained from appropriate combinations. The moving reflector introduces a factor $(c \pm v_r)/(c \mp v_r)$ into the formulas of Table I, and the following equations for these four cases result:

$$f_f = \frac{c+v_r}{c-v_r} \cdot \frac{c+v_d}{c-v_g} f, \tag{XIII}$$

an "enhanced up echo Doppler" effect;

$$f_f = \frac{c-v_r}{c+v_r} \cdot \frac{c-v_d}{c+v_g} f, \tag{XIV}$$

an "enhanced down echo Doppler" effect;

$$f_f = \frac{c-v_r}{c+v_r} \cdot \frac{c+v_d}{c-v_g} f, \tag{XV}$$

$$f_f = \frac{c+v_r}{c-v_r} \cdot \frac{c-v_d}{c+v_g} f. \tag{XVI}$$

Cases XV and XVI result in "echo Doppler" shifts that may be either up or down, depending on the relative values of v_g, v_d and v_r.

In Table II are collected the formulas for Cases XI to XVI. In this table, the algebraic sign of v_r in the numerator is positive when the reflector is approaching the generator and detector and is negative when the reflector is retreating. The sign of v_r in the denominator is always opposite to its sign in the numerator. The sign of v_d in the numerator is positive if the detector approaches the reflector and negative if it retreats. The sign of v_g in the denominator is always opposite to that of v_d in the numerator. Of course, v_d is numerically equal to v_g in the cases considered here.

CONCLUSION

All cases of Doppler and "echo" Doppler effect in which the generator, detector and reflector move along a straight path, so that no angles are involved that might alter relative velocities, can be combined into one formula, already given as expression (7) in Table II,

TABLE II. Doppler formulas for Cases XI to XVI; c, velocity of sound; f, frequency of generator; v_r, velocity of reflector.

Velocity of generator, v_g	Velocity of detector, v_d	Frequency received by detector, f_f	
0	0	$\frac{c \pm v_r}{c \mp v_r} f$	(4)
$\pm v_g$	0	$\frac{c \pm v_r}{c \mp v_r} \cdot \frac{c}{c \mp v_g} f$	(5)
0	$\pm v_d$	$\frac{c \pm v_r}{c \mp v_r} \cdot \frac{c \pm v_d}{c} f$	(6)
$\pm v_g$	$\pm v_d$	$\frac{c \pm v_r}{c \mp v_r} \cdot \frac{c \pm v_d}{c \mp v_g} f$	(7)

$$f_f = \frac{c \pm v_r}{c \mp v_r} \cdot \frac{c \pm v_d}{c \mp v_g} f. \tag{I–XVI}$$

Proper attention must of course be given to algebraic signs depending upon individual cases.

TO do hard things without show of effort, that is the triumph of strength and skill.—A. J. ROWLAND.

Precession of a Magnetic Top

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A SIMPLE demonstration experiment may be used to show the fundamental relationship between the precession of a rapidly spinning gyroscope and the external torque. To the author's knowledge this experiment has not been reported previously.

1. ELEMENTARY THEORY

Let us consider a symmetrical top rotating about a fixed point on its axis of symmetry. We suppose that at the time $t=0$ the top is spinning with an angular velocity $\mathbf{\Omega}$ about this axis and that the latter is inclined at an angle θ with respect to the vertical direction. We further suppose that the motion of the top is a steady precession with an angular velocity $\boldsymbol{\omega}$ and that this precession is *maintained* by a torque $\mathbf{T}$ acting normal to the vertical plane through the axis of symmetry. The discussion of our experiment requires the well-known relation between $\boldsymbol{\omega}$ and $\mathbf{T}$ that is valid for sufficiently large values of $\mathbf{\Omega}$.

If we assume that $\mathbf{\Omega} \gg \boldsymbol{\omega}$, then the direction of the total angular velocity vector $\mathbf{\Omega}+\boldsymbol{\omega}$ coincides approximately with the axis of spin and hence with a principal axis of the spheroid of inertia with respect to the point of support as origin; thus the angular momentum vector $\mathbf{p}$ also is in approximately the same direction as the axis of figure of the top. By combining the equation of motion with the expression describing the precession of $\mathbf{p}$ we obtain the vector equation,

$$\mathbf{T}=d\mathbf{p}/dt=\boldsymbol{\omega}\times\mathbf{p}. \quad (1)$$

If $\mathbf{r}$ is the radius vector from the fixed point to the center of gravity, then the gravitational force produces a torque,

$$\mathbf{T}_1=\mathbf{r}\times m\mathbf{g}=\mathbf{r}\times\mathbf{W}, \quad (2)$$

where m and $\mathbf{W}$ are the mass and weight of the top, respectively, and $\mathbf{g}$ is the acceleration due to gravity.

If a permanently magnetized rod is located coaxially with the axis of symmetry of the top, then the application of a uniform magnetic field $\mathbf{H}$ in the vertical direction produces a torque[1]

$$\mathbf{T}_2=\mathbf{M}\times\mathbf{H}, \quad (3)$$

where $\mathbf{M}$ is the magnetic moment of the rod in the field $\mathbf{H}$ and for the inclination θ. It is assumed throughout this paper that the induced magnetic moment in the remainder of the top is negligible. In addition, we assume, *for the present*, that the permanent moment $\mathbf{M}_0$ of the rod is directed along its axis and that the total moment $\mathbf{M}$ is substantially independent of $\mathbf{H}$ for fields smaller than the coercive field H_c. The vector $\mathbf{M}$ in Eq. (3) may thus be identified with $\mathbf{M}_0$, and the angle between $\mathbf{M}$ and $\mathbf{H}$ with θ or $\pi-\theta$.

The foregoing equations show that the angular velocities of precession caused by the torques $\mathbf{T}_1$ and $\mathbf{T}_2$ have the magnitudes $\omega_1=rW/p$ and $\omega_2=M_0H/p$, respectively. If both torques are acting simultaneously, then the resultant torque $\mathbf{T}=\mathbf{T}_1+\mathbf{T}_2$ produces a precession $\boldsymbol{\omega}=\boldsymbol{\omega}_1+\boldsymbol{\omega}_2$. It is obvious, therefore, that *the precession may be made more rapid, slowed down, stopped or reversed in direction simply by varying the magnitude of* $\mathbf{H}$ *or reversing its direction.*

For a certain value of $\mathbf{H}$ the total torque $\mathbf{T}$ vanishes and the precession stops ($\boldsymbol{\omega}=0$) because now the direction of $\mathbf{p}$ must remain constant. This situation will occur when the two torques are oppositely directed (as in Fig. 1) and

$$M_0H=rW, \quad (4)$$

an equation that is independent of θ.

Since the quantities appearing in Eq. (4) may be measured independently, the experiment may be made fairly quantitative by using this equation to check, for example, the value of M_0 by measuring the field that just stops the precession.

2. INDUCED MAGNETIZATION

The material of the ferromagnetic rod does not have to possess the somewhat idealized

[1] Some recent writers consider the field vector **B** to be the fundamental magnetic force vector. In our case, however, the torque $\mathbf{T}_2$ may just as well be written in terms of **H**, for in air **B** and **H** are practically equal.

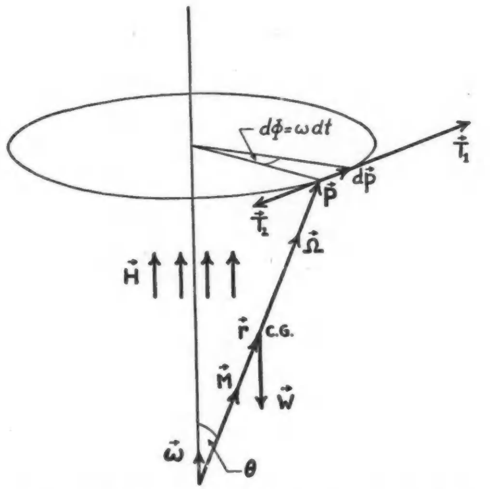

FIG. 1. Vector diagram illustrating a case where the magnitude of the gravitational torque exceeds that of the magnetic torque; the resultant precession is in the direction of that due to gravity.

characteristics which we have assumed while considering the principle of the experiment; it is not necessary that M_0 be large or that $\mathbf{M}$ be independent of $\mathbf{H}$ over a large range of fields. Almost any ferromagnetic substance may be used if sufficiently large fields are available. The dependence of the precession upon $\mathbf{H}$, especially the effect upon $\boldsymbol{\omega}$ of a reversal of $\mathbf{H}$, may be determined from the geometry of the rod and the hysteresis curve of its material. As an example, we shall discuss the case where M_0 is so small as to be practically zero; such a rod was actually employed in our experiment.

If the ratio l/d of the length of the rod to its diameter is sufficiently large (about 10), then we may assume that the moment $\mathbf{M}$ is directed along the axis of the rod. Since we are dealing with a material whose hysteresis loop has an area that is nearly zero, the angle between $\mathbf{M}$ and $\mathbf{H}$ is always equal to θ (never $\pi-\theta$). The magnitude M (which is now exclusively due to induction) depends, however, on both H and θ and will therefore be denoted by the symbol $M_{H,\theta}$. Instead of Eq. (4) we thus have

$$M_{H,\theta}\, H = rW, \tag{4'}$$

which may still be used for quantitative determinations as $M_{H,\theta}$ can be measured independently.

It is apparent that the direction of $\mathbf{T}_2$ is now always opposite to that of $\mathbf{T}_1$, so that the direction of the precession cannot be reversed by reversing the direction of $\mathbf{H}$. We can, however, slow down or stop the "gravitational precession," and even reverse its direction, simply by varying the magnitude H of the field. The precession may also be speeded up—that is, made larger than ω_1—but this is possible, of course, only in the "anti-gravitational" direction.

3. EXPERIMENTAL DETAILS

The magnetic field in this experiment was provided by an electromagnet whose pole pieces could be separated sufficiently to allow a small toy gyroscope and a wooden support for its axis to be placed between them, as indicated in Fig. 2. The current in the magnet and hence the field $\mathbf{H}$

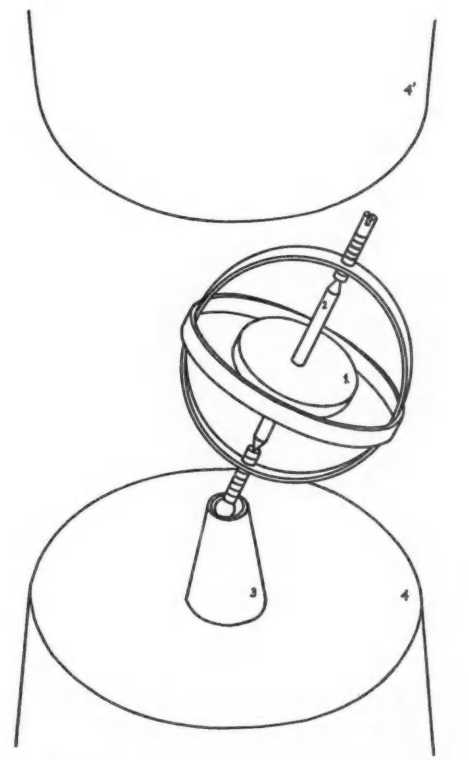

FIG. 2. Schematic diagram showing the spinning disk *1*, the ferromagnetic rod *2* and the wooden support *3* between the pole pieces *4* and *4'* of the electromagnet whose axis is in the vertical direction.

were adjusted by means of a series rheostat. A reversing switch was provided for demonstration purposes.

The gyroscope consisted essentially of a solid disk of about 4-cm diameter and 1.5-mm thickness mounted on an unmagnetized ferromagnetic rod which had a negligible remanent moment even after having been exposed to a field of a few hundred oersteds. The dimensions l and d of the rod were 4.3 and 0.44 cm, respectively. At the time of our first experiment (October, 1941) this gyroscope could be purchased for a few cents in a novelty store.

It was found that for an angle θ of about[2] 29° the precession could be stopped in a field[3] of 2.4×10^2 oersteds. Since r is 3.5 cm and m is 39.4 gm, Eq. (4′) furnishes the value $M_{H,\theta}=5.6\times10^2$ cgsm for the moment calculated from this experiment. A direct determination of $M_{H,\theta}$ was then carried out by measuring the induction B with a small search coil (which fitted closely over the rod) and a fluxmeter. It was assumed that the magnetization is uniform, and thus the moment was obtained by multiplying the intensity of magnetization, which is about $B/4\pi$, by the volume $V=0.65$ cm³ of the rod. The result of this determination was $M_{H,\theta}=4.9\times10^2$ cgsm for the same values of H and θ as those used in the gyroscopic experiment. It is seen that the calculated value is about 14 percent larger than the measured value, which we consider to be a satisfactory agreement in view of the inaccuracies inherent in this method.

A detailed discussion of experimental errors is obviously not warranted. We must point out, however, that the magnetic field was not as uniform as Fig. 2 may indicate. Another difficulty was caused by nutation, which increased, of course, as the spin of the top began to diminish. For these and other reasons the rheostat had to be adjusted almost continually after about 20 sec in order to keep the top from precessing. During the initial part of the demonstration, however, the field could be turned off and on several times and the state of zero precession was easily reproduced.

In conclusion we may point out that certain permanent magnet materials[4] possess a sufficiently high remanent induction and coercive field for an experiment of the type described in Sec. 1 of this paper. If, for example, "Alnico 2" could be used as the ferromagnetic material in a top similar to ours, then a reversal of the field would cause a reversal of the precession.

[2] This value represented the semi-angle of the conical pole pieces of the magnet, and thus it provided a convenient reference direction.

[3] The separation of the pole pieces was 12.6 cm and the magnet current 5.2 amp; currents up to 10 amp did not cause excessive heating.

[4] Pertinent data and further references on such materials are given by R. M. Bozorth, Am. J. Phys. 10, 73 (1942).

Book-Length Biographies of Physicists and Astronomers

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No one should be recognized a master in any subject who did not know at least the outline of its history. Of course it would be foolish to expect him to have any deep historical knowledge, but he should know the main landmarks and the leading personalities—he should be acquainted with his scientific ancestors.

This is almost a moral obligation. We might compare it to the obligation for any educated citizen to know the history of his country. The obligation is of the same kind and of the same order. . . . For a physicist not to be sufficiently familiar with Galileo and Newton is just as shocking as for an American not to know Washington and Lincoln.

THESE are the words of Dr. George Sarton,[1] the noted historian of science. A decade ago they motivated the present writer to take up what has proved to be a most satisfying and profitable avocation—to seek out, to read and to record:

I. All book-length biographies—individual and collected—in English of physicists, astronomers, mathematicians, chemists, metallurgists and engineers;

[1] G. Sarton, *The history of science and the new humanism* (Harvard Univ. Press, 1936), pp. 43–44.

II. All of the more important writings in English on the historical development of electrophysics and electrical engineering and on the lives and work of noted electrophysicists and electrical engineers.

Literal accomplishment of this program is, of course, virtually impossible; but it can be carried to a high degree of completion. And now that the hunt for material has encompassed search of (i) complete files of the consequential serial publications in English devoted to physics or to electrical engineering; (ii) the stacks and the card catalogs of most of the important public, university and technical libraries located in the East and Middle West; (iii) the accumulated catalogs of the principal publishers of technical and scientific books; (iv) the lists of offerings, over a decade, of the larger dealers in used and rare technical and scientific works; (v) much relevant miscellaneous bibliographic material—book review journals, printed catalogs of private libraries and kindred aids—it is believed that much the greater part of the more worthwhile material has been located and read. In consequence it seems desirable that this material now be made available to those similarly interested.[2]

At present the file devoted to items of category I contains some 700 titles; that devoted to category II, some 1500 titles. The bibliography below comprises the items of I apposite to physicists and to astronomers, together with a brief list of engineers and chemists who are frequently mentioned in textbooks on physics. Elsewhere are to appear separate bibliographies on mathematicians, on chemists and on metallurgists and engineers, and the complete bibliography of some 1500 titles on the historical development of electrophysics and electrical engineering and on the lives and work of the more noted of those who labored in these domains.

The writer will not attempt here to discuss what is to be gained through reading one, several or many of the books listed. His own views on the use of biographic material as a tool in teaching have been presented elsewhere.[3] Again, in several books[1,4,5] and in numerous papers published in *Isis* and in other journals, Doctor Sarton has discussed in detail the special values of the study of the history of science, mathematics and technology, and of the use of biographic material therein. Finally, in that they who undertake to read of the books listed below cannot fail to gain therefrom a considerable knowledge of the origins of various branches of physics, it is of interest to recall a pertinent remark of Ernst Mach:[6]

> They that know the entire course of the development of science, will, as a matter of course, judge more freely and more correctly of the significance of any present scientific movement than they who, limited in their views to the age in which their own lives have been spent, contemplate merely the momentary trend that the course of intellectual events takes at the present moment.

PHYSICISTS—INDIVIDUAL

A. M. Ampère, *The story of his love, being the journal and early correspondence of André Marie Ampère, with his family circle during the first republic, 1793–1804*, ed. by Madame H. C. (R. Bentley, London, 1873).

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* The phrase, "among others," signifies that these latter are not physicists.

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THE man of science appears to be the only man who has something to say, just now—and the only man who does not know how to say it.—SIR JAMES M. BARRIE.

A RESEARCH problem is not solved by apparatus, it is solved in a man's head. . . . The laboratory is the means by which it is possible to do the solving after the man has the idea clarified in mind.—CHARLES F. KETTERING.

An Experiment Illustrating Centripetal Force

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Most quantitative experiments involving centripetal force require complicated apparatus and also considerable manipulative ability on the part of the student. The apparatus described below was devised to illustrate in a simple yet quantitative way the role of centripetal force in the ordinary pendulum. The apparatus (Fig. 1) consists of a horizontal beam

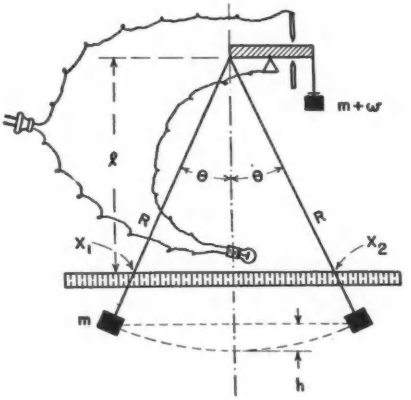

Fig. 1. Schematic drawing of centripetal pendulum.

from whose opposite ends two identical bobs are suspended, one by a thread about 10 cm in length, and the other by a thread about 60 cm in length. A horizontal razor-blade knife-edge supports the beam through a milled slot which is also the perpendicular bisector of the beam. As the center of gravity of the beam is above the point of support, the system is unstable and stops are provided on the short bob side by two vertical phonograph needles, one mounted above the beam and one below it (Fig. 1).

If the longer bob is allowed to swing in a vertical plane containing the long axis of the beam, the additional tension in the string causes the beam to tip until it rests against the top phonograph needle, which is electrically insulated from the rest of the apparatus, and this contact completes an electric circuit and lights a $\frac{1}{4}$-w neon bulb. Now, if an additional small weight is placed on the short bob, we find that the neon bulb remains bright over only part of the cycle and, as the amplitude of oscillation decreases, this fraction of a cycle decreases until finally the bulb no longer glows at all. At this point the centripetal force at the bottom of the swing is just equal to the excess weight placed on the shorter bob.

Now

$$w = mv^2/gR = m\cdot 2gh/gR$$
$$= 2mR(1-\cos\theta)/R = 2m(1-\cos\theta),$$

where w is the centripetal force in grams weight, m is the mass of the bob in grams, v is the linear velocity of the bob at the bottom of the arc, g is the acceleration of free fall, R is the length of the pendulum, h is the height of the center of mass of the swinging bob above its lowest position and θ is the maximum angle the thread makes with the vertical. The angle θ may be determined by judging at the ends of the swing the intersections x_1 and x_2 of the thread with a horizontal scale mounted a measurable distance l below the knife edge. Thus,

$$\cos\theta = l/[l^2 + \tfrac{1}{4}(x_2-x_1)^2]^{\frac{1}{2}}.$$

The damping of the motion is low, and the intersection need not be observed on the first swing. Even the second or third return to the position of maximum amplitude after the light has gone out permanently may be used with negligible

Table I. Typical data, for $l = 47.1$ cm.

w (gmwt)	x_1 (cm)	x_2 (cm)
5.0	64.0	80.5
10.0	60.3	84.0
15.0	57.2	87.2
20.0	54.5	89.7
25.0	52.0	92.3

$(1-\cos\theta) = 1/2m\ (w-w_0)$; slope $= (1-\cos\theta)/w = 1/2m = 0.081/24.5 = 0.00331\ \mathrm{gm}^{-1}$; m(calculated) $= 151$ gm; m(measured) $= 153$ gm.

error. Thus a plot of $1-\cos\theta$ *versus* several values of w, the excess weight, should yield a straight line of slope $1/2m$. Typical observations

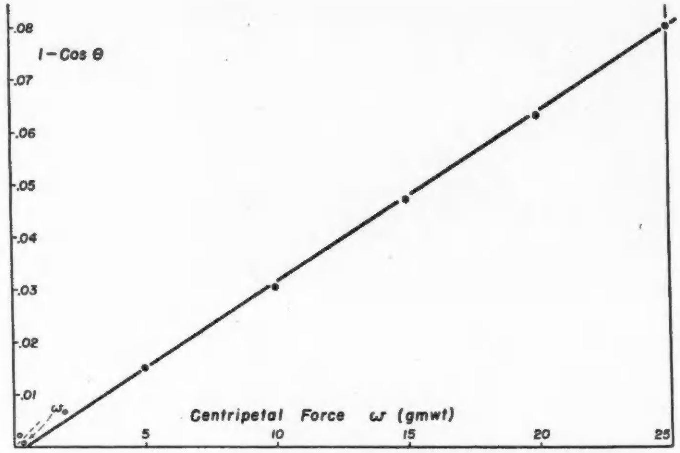

FIG. 2. Experimental curve, 1 − cos θ *vs.* centripetal force w.

and the curve obtained from them are shown in Table I and Fig. 2, respectively. The straight line does not go through the origin, and the intercept w_0 represents the difference in weight of the two bobs. The mass m of the bob as calculated from the slope of this line agrees to within 2 percent with the direct measurement on a balance.

Instructional Apparatus for Studying Pipe Flow

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INSTRUCTIONAL apparatus for studying the flow of water in a circular glass tube can serve several purposes. Such apparatus can be made to show easily and quickly the physical phenomena involved in the important practical problem of pipe flow, and can also illustrate some of the fundamental features involved in flow around bodies. It seems that it might be of value and interest to pass along some results of experience gained in developing one simple and inexpensive design.

APPARATUS

Figure 1 is a diagrammatic sketch of the apparatus. Water from an ordinary supply line enters the rear end of the rectangular tank. The tank can be made of galvanized sheet metal with one side glass. The water passes through the gravel baffle wall and then to the glass tube. The gravel baffle wall serves to prevent water supply disturbances from traveling to the glass tube and to reduce fluctuations in surface level in the downstream chamber. The glass tube is flared at the inlet to provide a smooth entrance.

The discharge valve A can be used to vary the rate of flow. The overflow pipe helps to maintain a constant level in the tank. A valve on the

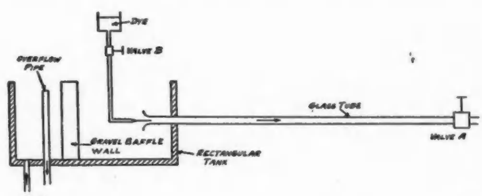

FIG. 1. Sketch of apparatus for studying pipe flow.

supply line is adjusted so that there is a slight flow over the top of the overflow pipe. Dye introduced at the inlet to the glass tube serves to render visible the nature of the pipe flow. A hypodermic needle or a converging glass nozzle

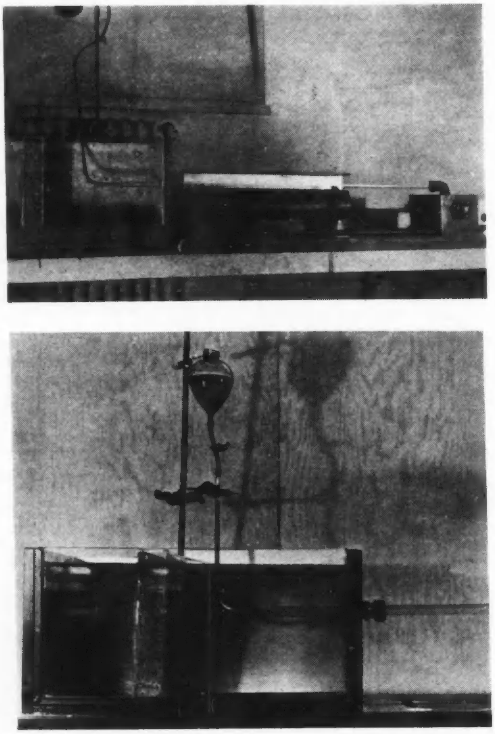

FIG. 2. Apparatus for studying pipe flow.

can be used, although the latter is less rugged for continued class use. Various chemicals can be used to form a dye solution with water; potassium permanganate is one possibility.

The valve (or adjustable pinch-clamp) B in the dye line is necessary, for the dye velocity at the inlet must be the same as the water velocity if there is to be no disturbance at the tip of the dye injector. The velocities can be compared simply by observing visually the flow at the tip.

Figure 2 shows photographs of this type of apparatus in the Purdue University fluid mechanics laboratory. Some idea of dimensions can be gained by noting that the tank is about 1 ft deep, 2 ft long and 1 ft wide. Glass tubes with internal diameters of $\frac{5}{8}$ and $\frac{3}{4}$ in. and a length of about 4 ft have been used. It is apparent that such apparatus need not be very expensive. Variations can be devised, depending upon available facilities and material.

USE OF APPARATUS

Laminar flow exists at low velocities; the dye filament is straight. As the velocity is increased the flow changes from laminar to turbulent, and the dye pattern becomes irregular; secondary motions are superimposed on the main flow along the axis of the tube.

Figure 3 shows some photographs of the flow obtained with the apparatus. The pictures are arranged in the order of increasing velocity; (*a*), with the lowest velocity, definitely shows laminar flow, whereas (*e*) and (*f*) show turbulent flow.

Lights and a reflector can be arranged behind the glass tube for demonstrations to large groups. Group experiments can be arranged, and quantitative results obtained that are in good agreement with published research data.

The type of pipe flow has been correlated with the dimensionless parameter called the Reynolds number R, which is defined as the ratio $VD\rho/\mu$, where V is the average velocity, D is the internal diameter of the pipe, ρ is the density and μ is

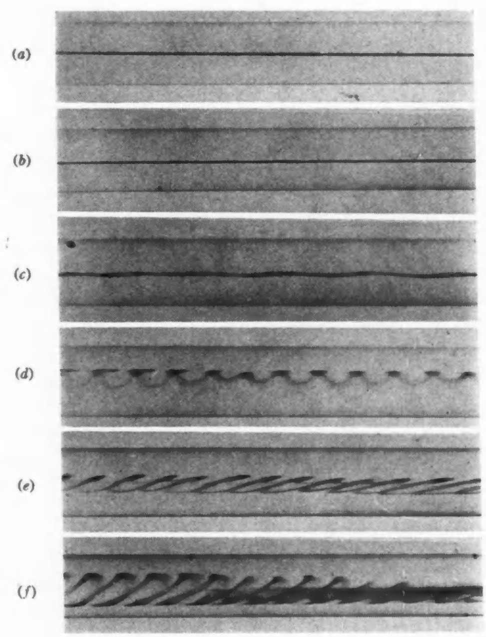

FIG. 3. Transition from laminar to turbulent flow with increasing values of velocity, for water in a glass tube.

the dynamic viscosity coefficient. The stable form of flow is normally laminar for R less than 2000; below 2000 an initially turbulent flow, with its typical irregular or eddying motion, cannot be maintained indefinitely. For usual conditions the flow is turbulent if R exceeds about 3000. In the transition region 2000 to 3000 there are various possible conditions, depending upon the nature of the pipe entrance and of the initial disturbances.

The water temperature and the diameter D can be measured; the dynamic viscosity coefficient μ and the density ρ can be found from tables. The weight-rate of flow through the glass tube can be measured with the help of a container, stop watch and scales. The velocity V can then be calculated from the weight-rate of flow and the internal area of the pipe. Valve B can be adjusted to obtain different rates of discharge, and for each valve setting the type of flow can be correlated with the corresponding Reynolds number. A scattered range of results obtained by a class can be employed to investigate critical values of the Reynolds number.

Laminar motion, turbulent motion and the transition from laminar to turbulent motion are general characteristics found in the flow around bodies and the flow through channels other than circular pipes. For example, the flow around a sphere is laminar at very low upstream velocities; the streamlines near the body are curved, but the flow is laminar. Turbulent flow is reached as the velocity is increased; irregular mixing and an eddying wake occur behind the sphere. Although there are some important differences between the flow in a circular pipe and that around a sphere, nevertheless there are certain general characteristics common to both flow patterns. The pipe flow apparatus serves to illustrate some of these characteristic phenomena. Study of them with simple apparatus expedites the student's understanding of the flow of fluids in general.

A Special Charging Rod for Demonstrations in Electrostatics

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THE essential features of this rod, which was designed for lecture demonstrations, are illustrated in Fig. 1. A brass tube, 10 in. long and $1\frac{1}{4}$-in. outside diameter, is covered by a cylindrical celluloid tube $\frac{3}{4}$ in. longer than the brass tube. This covering was constructed from a sheet of celluloid, 0.015 in. thick, which was rolled snugly around the brass cylinder and cut so as to leave a $\frac{1}{2}$-in. lap joint. The joint was carefully cemented on the inner tube. An ebonite handle 4 in. long is inserted into the free end of the celluloid tubing and held in position by means of an ebonite ring. The other end of the celluloid tube is held in place by means of a brass cap. This cap is electrically connected to the inner brass cylinder and serves as the terminal for the rod.

The rod is charged by holding it in the hand by means of the ebonite handle and rubbing it a few times with fur. This operation imparts a negative charge to the brass cylinder. When the rod is separated from the fur there is a marked decrease in the capacitance of the system with a corresponding increase in electric potential. This potential must be several thousand volts, for it is sufficient to give a spark discharge across a 0.3-in. gap between point electrodes. The charge

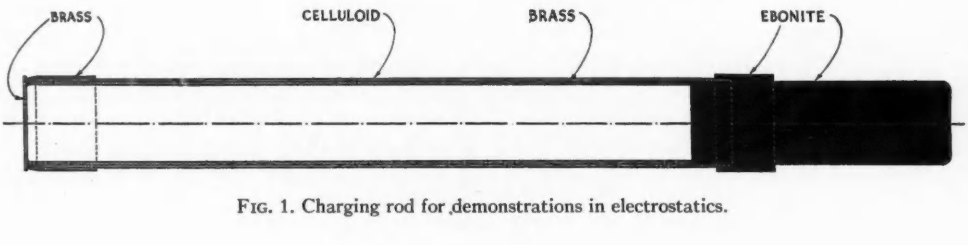

Fig. 1. Charging rod for demonstrations in electrostatics.

on the rod, measured by sharing it with a standard radio condenser connected to a calibrated electroscope, was of average value 0.2 μcoul.

This rod has been found to be more convenient than an electrical machine as a means of charging insulated conductors such as small spheres on insulating stands. It has also been employed to demonstrate currents from charges produced by tribo-electrification. For this demonstration the rod is charged and then touched to one of the terminals of a neon glow lamp. A momentary flash of light is secured in the lamp, indicating a flow of electricity therein. This shows up either with the neon lamp in a socket, with one terminal connected to ground, or simply with it held in the hand.

Another experiment was devised to show the trigger action of a preliminary discharge, in a circuit element between terminals in a gas, in initiating a steady current therein. A neon lamp is connected to the output terminals of a potentiometer rheostat which in turn is connected to a 110-v d.c. circuit. The emf applied to the lamp is adjusted to a value a little lower than that required for the initiation of the discharge. If the charged rod is now brought near to the lamp, it suddenly lights.

One condition which seriously impaired the efficiency of the charging rod was that of high relative humidity in the room due either to atmospheric conditions or to air conditioning. Under these circumstances a preliminary drying of the rod and fur was necessary. On account of the inflammable nature of celluloid, an important precaution to be observed while drying the rod is to keep it at a safe distance from gas flames.

This rod has proved to be more convenient for demonstration work than a paddle of ebonite or other insulating material in that it can be employed to charge objects either by conduction or by induction, whereas a paddle works satisfactorily only when charging by induction. It is better than a metal tube alone on an insulated handle, in that a larger charge is secured by rubbing fur on celluloid than by rubbing it on a metal surface. The details of construction can be varied considerably without impairing the efficiency of the rod. Satisfactory results have been obtained with quartz and ebonite tubes used in place of the celluloid.

An Elementary Conservation of Energy Experiment

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THIS experiment for the general physics laboratory tests the energy equation

$$Mgh=\tfrac{1}{2}MV^2+\tfrac{1}{2}I\omega^2, \tag{1}$$

where Mgh is the potential energy of a rolling object at the top of an inclined plane (see Fig. 1) and $\frac{1}{2}MV^2$ and $\frac{1}{2}I\omega^2$ are the kinetic energies of translation and rotation, respectively, at a point on the inclined plane at distance h below the release point. The apparatus is easy to construct and is inexpensive if there is available a timer giving 30 sparks/sec, such as that used in the familiar freely falling body experiment.

The inclined plane is made from a straight 2×6-in. piece of well-seasoned wood 6 ft long. Laboratory support rods screwed into the table mountings serve as a support for the upper end. The lower end hangs over the table a short distance. No stop is provided for the rolling object; the student simply catches it. Two parallel grooves 1 in. apart and running lengthwise are made in the board, and into these grooves are fastened metal strips, as in Fig. 1(*b*). It happened that we had showcase-door track available, and this was used for the metal strips. These metal strips are connected to the high potential terminals of the spark timer. Over one strip is placed a strip of 1-in. paraffined paper. As the metal object rolls down the incline a time record of its position is secured since a spark is made to jump periodically from one metal strip through the paper to the rolling object and back to the second metal strip. One of these strips is flush with the board; the other is about 1 mm below the surface, to provide the necessary air gap.

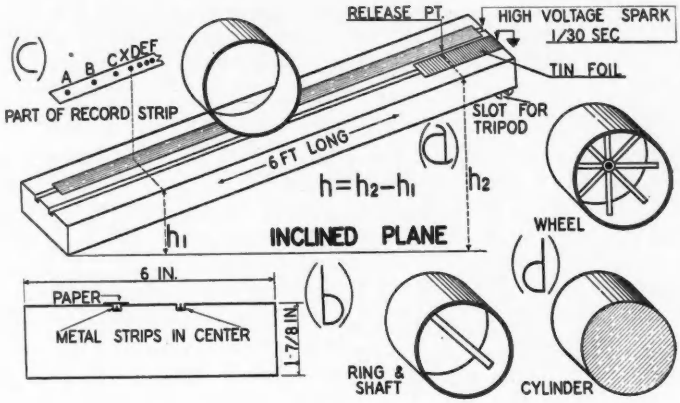

FIG. 1. Apparatus: (*a*) inclined plane; (*b*) section through inclined plane; (*c*) part of record strip; (*d*) other objects used.

To make sure that the student does not receive a shock when he starts the object down the incline, the object is started on a piece of tin foil which extends down from the grounded terminal of the spark timer for a short distance over the track flush with the board. The velocity V of the rolling object at a point X near the bottom of the inclined plane is determined by marking off six points A, B, C and D, E, F—three on each side of X, as in Fig. 1(*c*). The distance between adjacent points corresponds to a time interval of 1/30 sec. The velocity used is the average of the three velocities determined by taking the following distance-over-time quotients: $CD/(2/30)$, $BE/(4/30)$ and $AF/(6/30)$. The angular velocity ω is given by V/R, where R is the radius of the rolling object. The height $h[=h_2-h_1]$ is determined by measuring h_2 and h_1. It is important that the table be made level with a carpenter's level. The mass M is determined by weighing or, if the student prefers, the equation may be tested after M has been cancelled out in the cases where it is easy to do so.

Usually a thin ring or cylinder, for which I can be calculated from the dimensions, is used for the first part; and the student is required to find from experimental data the potential energy, the total kinetic energy and the percentage of difference between them. For the second part, the student assumes the correctness of Eq. (1) and determines the moment of inertia of a wheel or some other object [Fig. 1(*d*)] for which I is known from a previous experiment or can be calculated.

The physical set-up of the experiment is simple; yet, because of the opportunity afforded to clear up hazy and confused ideas about this all-important energy equation, often neglected in the laboratory,[1] the instructional value of the experiment is high.

[1] According to a study of 945 mechanics experiments in 63 laboratory manuals [W. V. Norris, Am. J. Phys. 6, 135 (1938)], ". . . an experiment dealing with energy directly is given in only one manual."

SCIENTIFIC journals are the circulatory system for the ideas of science. It is largely through them that science develops, for scientific growth is the result of cross-fertilization between laboratories and groups in different countries. One of the evil consequences of war is that it stops the flow of scientific ideas from one nation to another. And to the extent that this process is blocked the development of science is definitely retarded.—RAYMOND B. FOSDICK.

The Hope in Hopeless Cases

MORRIS GORAN
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SOME of the greatest minds in the world were once classified as dullards in school. Although a larger percentage of scientists always had high scholastic attainments, many of the most famous were among such seemingly hopeless cases.

The man who stands for much of physical science, Albert Einstein, is in the category. Until early adolescence, he showed no signs of becoming the Newton of his day. His teachers told his father that the boy was mentally slow and "adrift forever in his foolish dreams." The influence that swerved Einstein to develop his powers and rise to renown, the factor that helped him avoid the pitfall of believing the estimate of his early teachers, may have come from purposive social work. The present of a compass and friendly guidance in mathematics were probably directed actions intended for specific effects.

It is this kind of social work that must be performed by teachers to give the apparently backward and hopeless students every possible chance to redeem themselves. Often the removal of a single small obstacle is sufficient; occasionally, pressing personality and home difficulties must be obviated and these require more care, time, tact and intelligence than scores of teachers are able or are willing to expend. Yet some teacher or friend or relative did this for young James Clerk Maxwell and in return the world benefitted by his outstanding achievements in physics.

According to J. J. Thomson:

> [Maxwell] when he was ten years old . . . went to the Edinburgh Academy and was at first anything but a success. There were many reasons for this. He entered at the middle of the term; he had mixed very little with other boys and was naturally shy and awkward; he was not at all well prepared in school subjects and had a very strong Galloway accent, but worst of all he wore clothes designed by his father on what would now be called hygienic principles; he had a lace frill instead of a collar around his neck, a tunic instead of a coat, and square-toed shoes of a novel pattern, with a brass buckle. All these naturally called for vigorous protest, with the result that when he returned home the shirt of his tunic was missing and his frill was rumpled and torn. Things, however, slowly improved. Professor P. G. Tait who was his junior by one year at the academy says: 'At school, he was at first regarded as shy and rather dull. He made no friendships and spent his occasional holidays in reading old ballads, drawing curious diagrams and making rude mechanical models. This absorption in such pursuits, totally unintelligible to his school fellows, who were then totally ignorant of mathematics, procured him a not very complimentary name—Dafty. About the middle of his school career, however, he surprised his companions by suddenly becoming one of the most brilliant among them, gaining prizes and sometimes the highest prizes for scholarship, mathematics, and English verse.' [1]

Whoever, directly or indirectly, started Maxwell on the right road may not have had such intentions and may not have sensed a man of genius. Some say his father aided him. It may have been the stigma of a derogatory nickname with the resultant "I'll show them" attitude, kind words and deeds from an older friend, advice of a teacher or self-instilled wisdom after the bitter experience in maladjustment.

The same events can lead to the other extreme, with dormant talents in an oppressed individual. The world is fortunate in Maxwell's case, but others have been and are today being classed as hopeless and dull and backward, and lack the good fortune of proper molding events, or the guidance of a teacher able to direct abilities.

Justus von Liebig's experience is another with fruitful results. His biographer writes:

> As a schoolboy, Liebig was not a success from the pedagogic point of view . . . not only were all the acquirements that led to praise and honour in the school utterly out of his reach, but once the good Rector of the *gymnasium*, on the occasion of examining Liebig's class, made a most cutting and public remonstrance with him, reproached him for want of diligence, told him he was the plague of his teachers and the sorrow of his parents, and ended by asking what did he think was to become of him. Liebig . . . replied, amid the uncontrollable laughter of the good Rector

[1] *James Clerk Maxwell, a commemoration volume, 1831–1931* (Macmillan, 1931).

and of the whole school, 'That he would be a chemist.' No one at that time had any idea that chemistry was a subject that could be studied for itself. To most it was a mere accessory subject, at best a handmaiden to medicine and pharmacy; the idea of the study of chemistry being adopted as a career seemed preposterous.[2]

Liebig's father encouraged the boy by taking him to an apothecary for further training and allowing his son to help in his color-manufacturing business, which undoubtedly stimulated interest in the science.

Humphry Davy had difficulties in school life but was somehow wise enough to believe he was right in his dislikes and the school was wrong in its methods. He later wrote: "To learn in a natural manner is true pleasure; how evil it is that in most schools it only causes misery."[3] His formal training was at an end in his fifteenth year, and he became a physician's apprentice. If Davy had not somewhere at some time in his youth had the correct influences, either inadvertently or purposely, the world would have lost a remarkable scientist.

Isaac Newton was another who had difficulties in early school life. Only one student was scholastically lower than he at the first institution he attended. A fight in which Newton was victorious is generally supposed to have been the turning point in his intellectual life. The mathematician Évariste Galois, who lived but 21 years, could not convince either teachers or contemporaries of his worth. He was accused of "affecting ambition and originality";[4] he was considered a dull student. The same can be said of Augustin Fresnel who contributed so much to optical theory, as well as of some lesser-known laboratory workers. Perhaps when the facts of greater scientists' lives are less colored by ardent biographers, even more will be revealed as having belonged to the dumb-in-school category or, as it is sometimes interpreted, that of those who are too brilliant to be recognized as such by their teachers.

The time and patience involved in social work among hopeless cases is repaid many times over in the benefits to society which can accrue from the flowering of one among several hundred in similar dullard straits. A very large number of the others, perhaps unable to contribute to or advance knowledge, may be brought to a more normal level and lead happier lives. It should be a teacher's obligation to consider and try the technics of social work, with the aid of parents and physicians and psychiatrists, before giving up the student as beyond aid.

[2] W. A. Shenstone, *Justus von Liebig* (Macmillan, 1895).
[3] P. Lenard, *Great men of science* (Macmillan, 1938), p. 192.
[4] E. T. Bell, *Men of mathematics* (Simon & Schuster, 1937), p. 365.

Fall Meeting of the Oregon Chapter

THE Oregon chapter of the American Association of Physics Teachers met at the Oregon State College, Corvallis, on November 20, 1943. W. Weniger, President of the chapter, presided.

The meeting opened with an interesting and instructive symposium presented by well-trained teachers from other departments—high school, botany, chemistry, engineering and education—who are now helping with the teaching of physics in the Army training programs. These speakers graphically presented their views on the fundamental usefulness of college physics and discussed the difficulties of teaching physics with thoroughness and rare good humor. The consensus of opinion seemed to be that there was too much material, too many equations and concepts, to be presented adequately in the time allowed.

The organization of the laboratory work in general physics at the University of Oregon was described by Stanley Minshall, who has charge of this phase of the work at the university.

There were 30 present at a dinner held at the Hotel Benton. At an informal business meeting held during the dinner, it was decided to have three meetings during the present college year, one to be held at Salem, Oregon, early in 1944.

The group returned to the College for the evening session, where excellent papers were presented by L. E. Wilson, on "Methods of determining the age of the earth's crust," and by S. H. Graf, on "Technical applications of x-rays." Upon Professor Graf's kind invitation, the group visited his x-rays laboratory at the close of the session.

E. Hobart Collins, *Chapter Secretary*

NOTES AND DISCUSSION

Freezing Water by Evaporation

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To demonstrate the freezing of water at room temperatures, the pressure over the water is reduced by means of a pump. To absorb the water vapor, concentrated sulfuric acid is generally used,[1] but this may be objectionable for several reasons. Acid fumes are drawn into the pump. There is the danger of spilling the acid on the apparatus or on the experimenter's clothes and hands.

Anhydrous calcium chloride is a fairly satisfactory substitute for the acid. With calcium chloride and a Cenco Hyvac pump, a small quantity of water boiled in 45 sec and froze in $5\frac{1}{3}$ min. When the experiment was repeated with concentrated sulfuric acid, the water boiled in 30 sec and froze in $1\frac{3}{4}$ min.

Calcium chloride should not be used more than once—at the most, twice. Otherwise, the freezing time becomes excessive.

[1] Sutton, *et al.*, *Demonstration experiments in physics*, **H-70**, p. 215.

Coefficients of Friction Greater than Unity

B. W. Bartlett
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A not uncommon misconception among students of elementary physics is that the coefficient of static friction μ cannot exceed unity. That this misconception is not entirely limited to students is evidenced by the fact that I have more than once been asked by junior instructors if the coefficient could ever be larger than one. Apparently the less discerning confuse the tangent of the angle of repose with its sine, while more thoughtful individuals endow the coefficient of friction with the properties of the coefficient of restitution. The fact that the common inclined-plane type of laboratory apparatus for measuring the angle of repose normally reads only to 45° perhaps furthers the spread of this error.

That the coefficient of static friction can and does exceed unity may be very simply demonstrated with the use of an ordinary cubic Artgum eraser and a desk blotting pad. If a layer about $\frac{1}{4}$ in. thick is sliced from the eraser, this wafer will remain in equilibrium on the blotting pad at an angle of inclination as high as 60°, indicating that the coefficient of friction between eraser and blotter may be as large as 1.7. Incidentally, this value is approximately the same as that reported by Fountain[1] for dry rubber tires on dry glass. Fountain apparently was himself aware of the misconception which is the topic of the present note, for he says in his paper, "in both cases the force required to drag the loads was larger than that needed to lift them; that is, in both cases, the coefficient of friction exceeded unity. These experiments . . . show that it is possible for C [the coefficient of friction] to exceed unity without one of the surfaces being torn up. . . ."

Of some 20 elementary textbooks examined by the writer, only one[2] mentions specifically that the coefficient sometimes has values well in excess of one. In several cases tables of coefficients of friction contain statements such as, "Metals on metals (dry), 0.15—0.2." Actually, coefficients for dry metals run as high as 1.4, for aluminum on aluminum.[3]

Obviously the unwary demonstrator who tries to use the whole Artgum eraser instead of a relatively thin slice, will run into difficulty because the eraser (at least when new) is a cube. If the edges of the cube are parallel to those of the inclined blotting pad, the eraser will roll once the angle exceeds 45°. Even if the cubic eraser is placed so that the diagonal of its base parallels the incline, rolling will take place at an angle of about 55°. The rolling of the cube is an excellent illustration of the fact that the force of friction between two surfaces is independent of the area of contact, at least as a first-order effect. One can easily vary the angle of the plane slowly enough to show that, just as rolling starts, only the downhill edge of the eraser is in contact with the plane, yet no slipping occurs. The area of contact has been reduced to perhaps a hundredth of its former value without changing the force of friction sufficiently for the eraser to start slipping.

A variety of instructive problems involving this demonstration will no doubt suggest themselves to the reader. For example, one might ask what is the maximum height a that such an eraser can have and still start to slide before it starts to roll—assuming it has a square base whose sides are of length b. It is well within the capabilities of an average first-year physics student to show that the eraser will roll first if $b/a<\mu$, and will slide first if $b/a>\mu$.

* On leave of absence from Bowdoin College.
[1] C. R. Fountain, "The physics of automobile driving," Am. J. Phys. **10**, 322 (1942).
[2] C. W. Miller, *Introduction to physical science*.
[3] A. Gemant, "Frictional phenomena. XV," J. App. Phys. **14**, 457 (1943).

Modified Models—Aids to Teaching

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Slight changes in standard model equipment may improve its teachability or add to its sturdiness. Two such changes are added parts and eliminated parts.

(1) *Dowel axes in model airplane.*—The addition of wood dowels to a model airplane[1] renders visible the "axes of rotation" which are often mentioned, but sometimes remain nebulous. In Fig. 1, dowels of diameter $\frac{1}{4}$ in. have been inserted to represent the axes. An axis and the surfaces that control rotation about it are painted the same color to clarify the connection. Thus, motion of the red rudder causes the plane to yaw about the red vertical axis; that of the white ailerons initiates roll about the white longitudinal axis and that of the blue elevator causes the plane to pitch about the blue lateral axis.

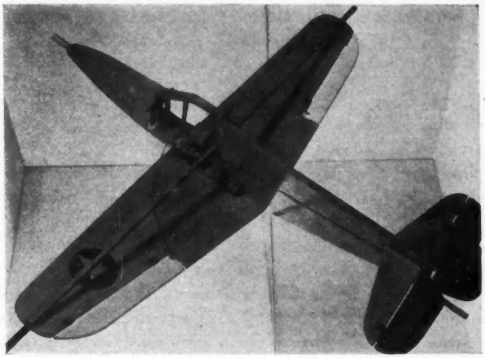

FIG. 1. Modified airplane model.

(2) *Teaching "scale" with models.*—The important concept of scale in applied mechanics[2] can be illustrated clearly by models, of which railroad cars are an example.

FIG. 2. Three models of a 40-ft car.

Such cars may be modified by the elimination of trucks and hardware, not generally available now. This elimination makes the models sturdy enough to be passed around for individual handling, as well as decreasing the cost. Figure 2 shows one each of three popular gages of a 40-ft refrigerator car,

$$O \text{ gage scale, } \tfrac{1}{4} \text{ in.} = 1 \text{ ft},$$
$$OO \text{ gage scale, } 4 \text{ mm} = 1 \text{ ft},$$
$$HO \text{ gage scale, } 3.5 \text{ mm} = 1 \text{ ft},$$

made with lithographed sides[3] and wood bodies.[4]

* Present address: Department of Electrical Engineering, U. S. Naval Academy, Annapolis, Md.

[1] Figure 1 is the "Comet Air-O-Trainer," Central Scientific Co. The kit includes all wood and working parts, also cement, but not the dowels or paint.

[2] R. C. Hitchcock, Am. J. Phys. 11, 161 (1943).

[3] Lithographed cardboard sides, ready to be cut out and cemented to car body; Champion Model Co., 3227 E. 65 St., Cleveland 4, Ohio.

[4] Cut-to-size car body kits include sides, ends, roof and floor, but not cement, trucks or hardware; Picard Novelty Co., 34 W. Broad St., Westerly, R. I.

Simple Illustrative Methods for Computing π

RALPH HOYT BACON
Frankford Arsenal, Philadelphia, Pennsylvania

ONE is occasionally asked by a nonmathematical colleague, as well as by elementary students, how π is computed. The mathematician knows of several series whose sum is π for some particular value of the argument. A few of these series can be derived by simple methods involving only a good knowledge of intermediate (third-semester secondary-school) algebra. The derivations are a bit longer, but no more difficult, than the familiar proof of the theorem about the area of the circle as given in elementary plane geometry. One would not ordinarily use some of the series thus derived for actually calculating π, as they converge too slowly, but the series do illustrate the method of computation.

We start with the relations,

$$\Sigma n = 1+2+3+\cdots+n = (n^2+n)/2, \tag{1}$$
$$\Sigma n^2 = 1+4+9+\cdots+n^2 = (2n^3+3n^2+n)/6, \tag{2}$$
$$\Sigma n^3 = 1+8+27+\cdots+n^3 = (n^4+2n^3+n^2)/4, \tag{3}$$

and so forth. These equations are quoted in various handbooks without proof. A simple proof is as follows:

$$\Sigma n^2 = n^2 + \Sigma(n-1)^2 = n^2 + \Sigma n^2 - 2\Sigma n + n;$$

therefore,

$$\Sigma n = (n^2+n)/2, \tag{1}$$

a well-known formula to begin with. Then,

$$\Sigma n^3 = n^3 + \Sigma(n-1)^3 = n^3 + \Sigma n^3 - 3\Sigma n^2 + 3\Sigma n - n;$$

therefore

$$\Sigma n^2 = (n^3 + 3\Sigma n - n)/3 = (2n^3+3n^2+n)/6, \tag{2}$$

and so on. Next, we observe that when n is a very large number Eqs. (1), (2), . . . reduce to the following very simple ones:

$$\lim_{n\to\infty} \Sigma n/n^2 = \tfrac{1}{2}, \qquad \lim_{n\to\infty} \Sigma n^2/n^3 = \tfrac{1}{3},$$
$$\lim_{n\to\infty} \Sigma n^3/n^4 = \tfrac{1}{4}, \qquad \lim_{n\to\infty} \Sigma n^m/n^{m+1} = 1/(m+1).$$

The last relation holds for all positive values of m, but we need only the even powers for the present discussion.

Now, take a circle of radius r, and divide it into quadrants. Then, as shown in Fig. 1, divide one radius into n equal segments, where n is a very large number. Erect perpendiculars to the radius at the ends of each segment, thus dividing the quadrant into n narrow strips. The sum of the areas of these strips is the area of the quadrant. The width of each strip is r/n, and the height of the kth strip is $r[1-(k/n)^2]^{\frac{1}{2}}$. Then,

$$\text{area of } k\text{th strip} = \frac{r^2}{n}\left[1-\left(\frac{k}{n}\right)^2\right]^{\frac{1}{2}}$$
$$= \frac{r^2}{n}\left[1 - \frac{1}{2}\left(\frac{k}{n}\right)^2 - \frac{1}{8}\left(\frac{k}{n}\right)^4 - \cdots - \frac{1\cdot3\cdot5\cdots(2m-3)}{2^m m!}\left(\frac{k}{n}\right)^{2m} - \cdots\right];$$

$$\text{area of quadrant} = r^2\left[1 - \frac{1}{6} - \frac{1}{40} - \cdots - \frac{1\cdot3\cdot5\cdots(2m-3)}{2^m m!(2m+1)} - \cdots\right] = \frac{\pi r^2}{4};$$

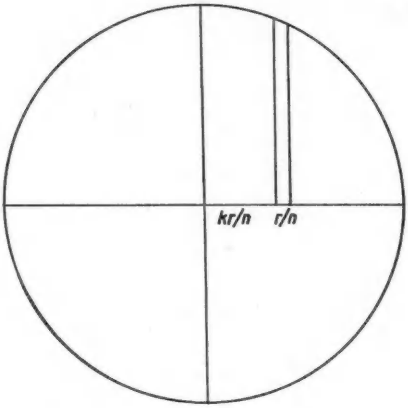

FIG. 1. The quadrant of a circle of radius r may be divided into n strips of width r/n and height $r[1-(k/n)^2]^{\frac{1}{2}}$. If n be a very large number, each strip may be regarded as a rectangle. However, should one desire to regard the strips as trapezoids, he would still obtain the same expression for the area of the quadrant.

therefore,

$$\pi = 4 - 2/3 - 1/10 - 1/28 - 5/288 - 7/704 - 21/3328 - \cdots.$$

This series converges too slowly for practical use; a tremendous number of terms is needed to obtain a reasonable value of π. For example, the sum of the first twelve terms is 3.15128.

We can get another series for π by finding the length of the arc of the quadrant. In the limit, each element of arc, ΔS_k, is the hypotenuse of the right triangle whose base is r/n, and whose altitude is the difference between the heights of two successive ordinates, so that

$$(\Delta S_k)^2 = \left(\frac{r}{n}\right)^2 + r^2\left\{\left[1-\left(\frac{k}{n}\right)^2\right]^{\frac{1}{2}} - \left[1-\left(\frac{k+1}{n}\right)^2\right]^{\frac{1}{2}}\right\}^2.$$

Upon expansion of the radicals in the (square) brackets, subtraction and reduction, this leads to the series

$$\pi = 2 + 1/3 + 3/20 + 5/56 + 35/576 + 63/1408 + 231/6656 + \cdots.$$

This series converges even more slowly than the previous one.

We can obtain still another series for π by finding the length of the arc whose sine is $\frac{1}{2}$, if we divide the radius of the circle into $2n$ segments, so that $r \sin \pi/6$ is divided into n segments, and the element of arc, ΔS_k, is the hypotenuse of the triangle whose base is $r/2n$, and therefore

$$(\Delta S_k)^2 = \left(\frac{r}{2n}\right)^2 + r^2\left\{\left[1-\left(\frac{k}{2n}\right)^2\right]^{\frac{1}{2}} - \left[1-\left(\frac{k+1}{2n}\right)^2\right]^{\frac{1}{2}}\right\}^2$$

and

$$\pi = 3 + \frac{1}{8} + \frac{9}{640} + \cdots + \frac{3\cdot 1\cdot 3\cdot 5\cdots(2m-1)}{2^{3m} m!(2m+1)} + \cdots.$$

This series converges much more rapidly. For example, the sum of the first five terms is 3.1415111, and the sum of the first seven is 3.1415889···.

Photometrics in College Physics Textbooks

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IN a recent article[1] attention has been called to the antiquated presentation of photometrics in college physics textbooks. The criticism offered by the authors is sound, and their constructive suggestions are very challenging. They have brought considerable clarification and meaning into the subject, and at the same time have simplified the terminology and concepts. The concepts of flux, or energy flow per unit time, and flux density, or energy flow per unit area and time, are important not only in light but also in sound and should be understood by the student. Generally speaking, students have little difficulty with these concepts when they are explicitly stated. It is the terminology—illumination, luminosity, candlepower, and so forth—that frequently causes difficulty, largely because these words are used without being given their scientific definitions. There is no question that a considerable improvement would be effected if one could limit the discussion of the subject to the four quantities suggested; namely, radiant flux (watts), radiant flux density (watt/m²), luminous flux (lumens) and luminous flux density (lumen/m²), thus omitting candlepower, footcandle, and so forth. Is one, however, at liberty to discard these latter terms because candles belong to a bygone age? Unfortunately, it does not appear generally to be the case that, as the authors suggest, "the rating of lamps in terms of their luminous flux expressed in lumens, is familiar to the average user today." Rather, the average user is familiar with candlepower and footcandles. Until such time as lamps are commonly rated in lumens or lumens per watt and light meters rated in lumens per square meter, it would appear that college textbooks should not discard candles. This would imply presenting the relationships between the units, which can be done directly or by defining mean spherical candlepower as lumens per unit solid angle. If uniformly radiating point sources of light are assumed, somewhat as one assumes point masses or point charges, the relationship between 1 ft-candle and 1 lumen/ft² or 1 lumen/m² can be easily obtained.

It might also be argued that the unit of luminous intensity, the international candle, should be given, together with methods of comparing the luminous flux from different sources. If, as is suggested, the photometer is to be discarded, then some other method—for example, the Ulbricht sphere—should be included. This raises the question whether it is not desirable to give a description of one of the methods used to establish the relationship between radiant and luminous flux, that is, to describe how the lamprosity curve was obtained.

Since it is true that many of the presentations of photometrics are antiquated, it is articles such as the one referred to that will bring about improvement in the presentation and are most welcome to teachers.

[1] P. Moon and D. Spencer, Am. J. Phys. 11, 201 (1943).

Friction on Variable Slope: A Correction

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College of Agriculture, University of California, Davis, California

Dr. Wm. T. Thomson, of Cornell University, has pointed out an omission in the recent note[1] on this subject. The normal force N should have been defined as total thrust of the body against the incline, including a centrifugal reaction term mv^2/r. The first equation in the previous note will then read as follows:

[1] W. P. Berggren, Am. J. Phys. 11, 109 (1943).

$$\text{Work against friction} = \int \mu\left(mg\frac{dx}{ds} + m\frac{v^2}{r}\right)ds$$
$$= \mu mgx + \mu m\int \frac{v^2}{r}ds, \quad (1)$$

where the radius of curvature r of the path is to be taken as positive when the curve is concave on the upper side. On account of the presence of the second term in Eq. (1), no simple explanation for the speed can be obtained. An approximate solution for the curve of Fig. 1 in the previous note indicates a speed correction of about 15 percent at the first point of inflection.

NECROLOGY

W. J. Kennedy, 1900–1943

Dr. W. J. Kennedy was born in Eldorado, Oklahoma, on October 16, 1900. He received the degree of Bachelor of Science in 1926 from Oklahoma Central State Teachers College, and in 1929 he was awarded the degree of Master of Science by the University of Oklahoma. In 1928 he was appointed to the staff of Trinity University as Assistant Professor of Physical Sciences. In 1941, following graduate work at the University of Chicago and the University of Texas, he was awarded the Ph.D. degree by the latter institution.

Doctor Kennedy's research was in the field of precision acoustical measurements, his most important work being the adaptation of optical technics to the measurement of sound pressure in air. In this work he exhibited those rarer traits of persistence in the face of experimental difficulties and of insight into the intricacies of absolute measurements which are so necessary to experimental research in this field of physics.

In his teaching, both at Trinity University and at the Sam Houston State Teachers College, whose staff he joined not long before his death, Doctor Kennedy was well known for his leadership and inspiration of his students in physics and for the excellence of his lectures. He had the unusual ability of incorporating into his lecture material both the fact and inspiration arising from his reading and research. Much of this material might otherwise have been of the unfortunate kind thought of as necessary but uninspired.

The passing of Doctor Kennedy, particularly at the period of his greatest productivity and usefulness as research man and teacher, is a distinct loss to our profession.

C. P. Boner

Arthur P. R. Wadlund, 1895–1943

The untimely death, on September 1, 1943 of Professor Wadlund at the age of 47, takes from us a good physicist and a man of high character much valued by a wide circle of friends. His genial presence will be greatly missed at the meetings of the American Physical Society and the American Association of Physics Teachers. A host of his former students will mourn the passing of one to whom they owe so much.

Arthur P. R. Wadlund was born in Brooklyn, New York. His parents moved to Hartford when he was only six years old. He attended Hartford Public High School and Trinity College where he led his class. He was elected to Phi Beta Kappa, was awarded the valuable Holland Scholarship, and when graduated in 1917 he received the Terry Fellowship for graduate study. This, however, had to be postponed, because he enlisted in the 101st Machine Gun Battalion of the Yankee Division and served overseas first as private and later as sergeant, winning the Distinguished Service Medal with five bars for five major engagements.

For the four years following the war Wadlund worked as metallurgist for the Greenfield Tap and Die Company, and then for the Henry Souther Engineering Company in Hartford. In 1923 he was appointed assistant professor of physics in Trinity College, later associate professor and finally, in 1942, full professor and head of the department. During the years from 1923 to 1928 he worked for his doctorate at Chicago in summer sessions and for the entire academic year of 1927–1928.

In 1928 Wadlund won his Ph.D. sponsored by Professor Arthur H. Compton, under whose direction he had completed a valuable piece of research on x-ray wave-lengths measured with a ruled grating. This was later followed by some remarkable Laue spot photographs, made in the Trinity College laboratory, showing radial lines which helped to inaugurate intensive work on the fine-structure of Laue patterns in Europe, India and America.

Because of his ability in the field of x-rays, Wadlund was asked to take the position of consulting physicist at the Hartford Hospital. To fit himself for this post he spent some months in the Memorial Hospital of New York City, working in the field of radiology under the direction of

Mrs. Edith H. Quimby. As a result he became well known in that field throughout Connecticut, and served the Hartford Hospital until his death.

In the field of experimental physics, Wadlund was painstaking and meticulous to a fault. Nothing but perfection in detail satisfied him. He never jumped at conclusions, but with clear insight and critical acumen dug to the bottom of his problem. Such self-criticism meant fewer publications than he could otherwise have produced, but the work he did turn out was of the best.

As a teacher Wadlund was just as conscientious as in the laboratory, so much so indeed that a class once complained bitterly that he never gave them a cut! But he made up for such unpopular rigor by his kindness in helping all who came to him with their difficulties, devoting extra time to his weekly "clinics" for the "lame ducks" and taking infinite pains with all of his classes whether elementary or advanced. He had the quality, rare among men of high mentality, of being really interested in the mediocre student, because he combined human sympathy with intellectual power. Such a combination makes for a "good teacher," and Professor Wadlund fully deserved that fine distinction.

Henry A. Perkins

William Edward McElfresh, 1867–1943

Professor William E. McElfresh died suddenly June 2, 1943 at his home in Williamstown, Massachusetts at the age of 75. Having come to Williams College in 1901, he was so successful as a teacher and administrator in the department that in 1905 he was made Thomas T. Read professor of physics. He was chairman of the physics department until 1931 and retired as professor emeritus in 1936.

Professor McElfresh was primarily a teacher, spending the major portion of his time and energy in a clear, thorough presentation of the subject of physics in formal class work, in individual conferences with students and in preparing written material for student use. He measured his success by the success of his students in graduate physics and engineering, and the small but steady stream of such students gave him great satisfaction. He was not a "popular teacher" because, at the height of his career, that term meant one who gave high grades for some effort but had few requirements as to understanding. However, he was considered thorough and fair, and was highly respected by the students. His demonstration lectures were always received with enthusiasm, and many a student elected to suffer through the "hardest course in college" just to have the privilege of attending McElfresh's lectures. Only once, to the writer's knowledge, did an experiment fail for him and that was a demonstration of three-phase alternating current, when the power lines had been shut off after the lecture started. The infinite care in preparation that this unfailing success implies was characteristic of the man in all matters pertaining to teaching.

Professor McElfresh was born October 5, 1867 at Griggsville, Illinois. He secured the A.B. degree from Illinois College in 1888 and the A.B., A.M. and Ph.D. degrees from Harvard in 1895, 1896 and 1900, respectively. During the years he was at Harvard he held, at various times, an assistantship in physics, an Austin teaching fellowship and an instructorship at Radcliffe.

On two occasions, after he received the doctorate, he took leaves of absence to carry on research at the Cavendish Laboratory, once in 1913–14 and again in 1924. His primary objective in this research was to "keep himself alive" in the field so that his teaching should not suffer from stagnation. He frequently made extensive visits to laboratories in this country and in Europe for the same reason.

He was very successful as a lecturer before a general audience and was sought out for such lectures by his colleagues on the faculty whenever a new field of physics came to the attention of the public. One of his colleagues in history once remarked that McElfresh almost made you believe that you understood relativity, quantum theory, atomic transmutations or whatever subject he dealt with in his lecture.

He had a remarkable memory for names, faces and incidents, and many a man returning to the campus for a visit has been pleased and flattered because Professor McElfresh remembered so much about him. The same trait gave encouragement to young physicists at meetings of the Physical Society when, upon encountering them, Professor McElfresh would comment on papers they had previously published or presented before the Society.

He was very active in the general intellectual and administrative activities of the college and gave particularly valuable service on the committee that studied the curriculum and recommended changes to meet the needs of a changing world. He was chairman of this committee for over 20 years, in a period of constant legislation and controversy. He steered a steady course, prepared business with keen insight and efficiency and presented the committee's conclusions to the faculty with a clarity and impartiality that could not be surpassed. In the hottest contests he kept his temper and good humor. The problems considered by this committee interested him greatly and he considered that the decisions served only as a guide in the general educational process. Education was, to his mind, a living, growing system that could not be reduced to a formalism of prescribed rules and methods.

Professor McElfresh was a charter member of the American Association of Physics Teachers, a fellow of the American Physical Society and a member of the American Association for the Advancement of Science. He will be sincerely missed by his many friends both on the Williams campus and in the societies whose meetings he attended regularly.

Ralph P. Winch

DIGEST OF PERIODICAL LITERATURE

"Joule" Rhymes with "Rule"

A difference of opinion unfortunately has arisen about the correct pronunciation of Joule's name and also of the word *joule* used to denote the energy unit, 1 newton meter. Although several dictionaries give *jowl* as the correct pronunciation, there appear to be good reasons for believing that Joule and his relatives pronounced it *jōōl*. The suggestion is made that the pronunciation *jowl* "may have originated in Salford through the sardonic humor of local workpeople who, having in mind such an expression as 'cheek by jowl,' spoke of 'Jowle's brewery.'" For the unit of energy, the pronunciation *jōōl* also has the advantage that it is immediately applicable in French; compare the words *boule* and *jour*. H. S. Allen, *Nature* **152**, 354 (1943).

According to P. G. Tait, who worked with him, Joule gave the *ou* in his name the sound of *ou* in *you*.—Joseph O. Thompson, *Science* **77**, 88–89 (1933). D. R.

Laboratory Work and the Scientific Method

Five suggestions are given for teaching in the laboratory the scientific approach to a problem. (1) The experiment should include an unknown, so that the student is compelled to make observations and draw conclusions therefrom. (2) Detailed directions for carrying out an experiment should be avoided to encourage the student to exercise his own judgment. (3) Questions dealing with background material should be segregated from those that are to be answered on the basis of experimental results. (4) The results to be expected from an experiment should not be included in the directions. (5) Experiments should be so designed that the student can use the results of certain experiments to plan future work.—W. B. Thomas, *J. Chem. Ed.* **20**, 379–380 (1943). J. D. E.

A Cyclotron Model

A model to illustrate the motion of ions within the dees of a cyclotron consists of a square box with a plywood top in which has been cut a spiral slot ending in a short tangential portion. Beneath the top is a plywood disk free to rotate on an axle made of a dowel pin. The disk carries a radial slot and is turned by a string passing around the circumference of the disk in a groove and around a pulley driven by a small motor mounted in one corner of the box. Light from an electric lamp within the box passes through the radial slot in the disk and the spiral slot in the top to a sheet of paper laid on the top and bearing a diagram of the dees and electrodes. The deflecting electrode and the target may also be indicated. As the disk rotates several spots of light move in the characteristic spiral path of the ions and with increasing speed as they recede from the center.

In order to show the signs of the potentials on the dees, the disk carries two semicircular slots of slightly different radii, that lie on opposite sides of the diameter containing the radial slot. Above these slots two plus and minus signs are cut in the top, beneath the positions of the electrodes on the diagram, in opposite orders. These signs appear lighted next to the electrodes and reverse twice in each rotation of the disk and at the moment when the "ions" pass from one dee to the other. A sheet of tissue paper between the disk and the lamp serves to diffuse the light and reduce undesirable shadows.—E. E. Grassel, *J. Chem. Ed.* **20**, 460–461 (1943). J. D. E.

Reverberation in Small Glass Tubes

If an 8-cm length of Pyrex capillary tubing, of bore 0.7 to 4 mm, is melted at one end and a 1-cm bulb blown, during blowing and afterwards the tube will emit a note whose frequency depends mainly on the diameter of the bulb but also on its temperature and the stem length. If the bulb is thick-walled, the note may last for 1 min or more; or if the bulb is held in the flame at about 700°C, the note may last indefinitely, or until the bulb collapses. Evidently the oscillation starts in a way reminiscent of the troublesome oscillations that make Clément and Desormes' classical experiment on the ratio γ so difficult; and it is sustained because cold air sucked in during a half-cycle is heated and driven out at increased volume. Roughly, one may suppose that the condition for sustained oscillation is $\Delta T/T > 3r^2h/4R^3$, where ΔT is the temperature increase of the air, r and R are the radii of the bore and bulb, respectively, and h is the stem length. The frequency probably is proportional to the rate of heat transfer from the hot bulb per unit volume of air, and hence proportional to $1/R$. If R is 1 cm, the note is low, near the limit of audibility; thus the production of audible frequencies is limited to small tubes.—Shaun M. Cox, *Nature* **152**, 357–358 (1943). D. R.

A Plea for English Units*

The use of a unit volume of water to furnish the unit of weight was the basis of both Greek and Roman systems. Moreover, it was the forerunner of the present English system. The master craftsmen of Lübeck, chief city of the Hanseatic League, made the weight of 1 ft³ of ice water equal to 1000 oz, 16 of which gave the pound. This ounce is equal to 437 grains, and there are 437,000 grains in 1 ft³ of water at 0°C; this value, which was accurate to six significant figures, was somewhat spoiled in Queen Elizabeth's time, when the ounce was made equal to 437.5 grains. Nevertheless, 1 ft³ of water weighs 999 oz at 4°C and 997.2 oz at 20°C; the corresponding figure in the metric system is 998.2 gm/l. Thus when temperature is neglected, the density of water may be taken as 1000 oz/ft³ just as well as 1000 gm/l. Similarly, the weight of dry air under standard conditions is 1.293 kg/m³ and 1.292 oz/ft³. Multiplying the value of the density of a solid in grams per cubic centimeter by 1000 gives the density in ounces per cubic foot; if the ov (ounce-volume), or 0.001 ft³, were used for the unit volume, as has been suggested, densities would have the same numerical value

in grams per cubic centimeter and in ounces per ov. The ounce molecular volume is 22.4 ft^3; the gram molecular volume is 22.4 l. Conversions from one system to the other are facilitated by the fact that 1 oz = 28.3 gm and 1 ft^3 = 28.3 l. In the equation $pv = NRT$, R will have the same value whether v is in liters and N in gram molecular weights or v in cubic feet and N in ounce molecular weights.—K. G. Irwin, *J. Chem. Ed.* **20**, 464–465 (1943).

J. D. E.

* See also K. G. Irwin, Sch. Sci. and Math. **39**, 126 (1939) [digest in Am. J. Phys. **7**, 270 (1939)].

Check List of Periodical Literature

Henson, inventor of the airplane. A. F. Zahm, *J. Frank. Inst.* **236**, 235–239 (1943). In 1842 Henson was awarded a British patent for a power-driven airplane "covering all, and more than all, the organs essential to pioneer flying."

Otto von Guericke: a neglected genius. T. Coulson, *J. Frank. Inst.* **236**, 241–264, 333–351 (1943). "He combined his scientific activity with a public life that justifies comparison with Leonardo da Vinci and Benjamin Franklin."

How can we improve engineering books? J. S. Thompson, *J. Eng. Ed.* **34**, 193–203 (1943). The author is an officer of the McGraw-Hill Book Company.

Notes on some recent developments in hygrometry. J. H. Awbery, *J. Sci. Inst.* **20**, 153–154 (1943).

The nature and purpose of physics as applied to some railway problems. T. A. Eames, *J. Sci. Inst.* **20**, 169–175 (1943). Included in this interesting article is a discussion of the special qualities which a physicist may be expected to bring into industry and the type of work on which he may most profitably be employed.

The early history of the electron microscope. *J. App. Phys.* **14**, 434–436 (1943).

The American Institute of Physics building. R. V. Hutchisson, *J. App. Phys.* **14**, 501–509 (1943). The early history of the building; profusely illustrated.

Problems of the scientific literature survey. G. Egloff, M. Alexander and P. Van Arsdell, *J. Chem. Ed.* **20**, 393–398 (1943). Contains detailed suggestions for conducting a thorough and complete literature survey in search of information on a particular topic.

The concept of color. Committee on Colorimetry, *J. Opt. Soc. Am.* **33**, 544–545 (1943). The second chapter of the forthcoming Colorimetry Report.

Man's most creative years: then and now. H. C. Lehman, *Science* **98**, 393–399 (1943). Although knowledge is becoming more complex and the average length of life is increasing, there is no evidence to support the idea that present or future generations of highly creative thinkers will attain their peak output at increasingly older age levels. Indeed, physicists born from 1785 to 1867 were somewhat younger at the time of their greatest contributions than were those born earlier.

Tennyson's prediction of the invention, use and misuse of the airplane. M. F. A. Montagu, *Science* **98**, 431 (1943). The 11 relevant stanzas from "Locksley Hall" (1842) are quoted.

Annual Report of the Treasurer, American Association of Physics Teachers

Balance brought forward from Dec. 15, 1942		$ 6,928.36
Cash Received		
Dues received for 1943[1]	$4797.50	
Dues received for 1942	85.00	
Dues received for 1944	265.00	
Dues received for 1945	10.00	
Royalties, *Demonstration Experiments in Physics*	274.51	
Membership fee for A.C.E., paid by American Institute of Physics	100.00	
American Institute of Physics report at June meeting	10.00	
Donations	33.23	
Total deposited, 12/15/42 to 12/15/43		5,575.24
Total cash available		$12,503.60
Disbursements		
Postage and supplies	$ 191.17	
Printing	156.70	
Stenographer, editor's office	816.00	
Secretary's office expense	410.89	
Constituent membership in A.C.E.	100.00	
Editor's traveling expense	42.99	
Payments to American Institute of Physics	3460.49	
Traveling expense, Richtmyer Memorial lecturer	25.00	
Discount on checks	2.92	
Purchase of Government Bonds	5000.00	
Miscellaneous	8.29	
Total disbursed		10,214.45
Balance on hand Dec. 15, 1943[2]		$ 2,289.15

Paul E. Klopsteg, *Treasurer*

I have audited the books of account and records of Dr. Paul E. Klopsteg, Treasurer of the American Association of Physics Teachers, for the year ended December 15, 1943, and hereby certify that the foregoing statement of receipts and disbursements correctly reflects the information contained in the books of account. Receipts during the year were satisfactorily reconciled with deposits as shown on the bank statements, and all disbursements have been satisfactorily supported by vouchers or other documentary evidence.

William J. Luby
Certified Public Accountant

Chicago, Illinois,
December 21, 1943.

[1] On December 15, 1943, there were 1001 members in good standing.
[2] A balance of approximately $900 is due the American Institute of Physics for the publication of the journal in 1943.